Modeling fire behavior in beetle-kill fuels: on the frontiers of fire science and disturbance ecology

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Mountain Pine Beetle and Wildfire Forum
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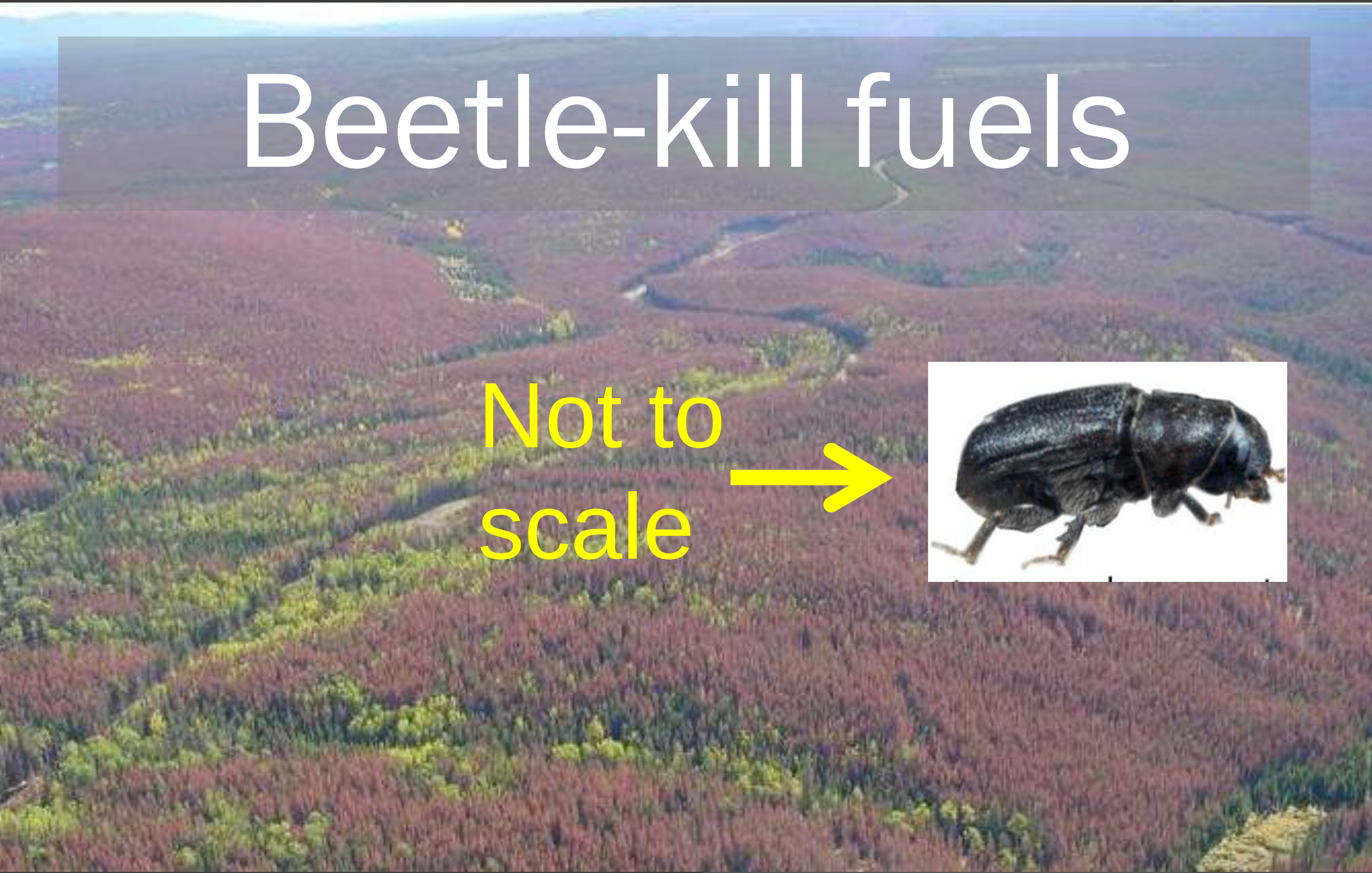
United States Department of Agriculture – Forest Service
Rocky Mountain Research Station

Beetle-kill fuels



Not to scale

How <u>does</u> beetle-kill affect fire behavior??

- Literature offers conflicting results – why?

1. Lack of fundamental data
2. Perspective confusion: immediate vs later in time

   Immediate → Later in time

3. Difficult to separate environmental conditions from fuels states for real fires
4. Models used to answer these questions were not designed to handle these situations

Expected fire behavior changes from in beetle-kill fuels

We can demonstrate that …

- **Red trees: drier, ignite faster**
- **Faster heat release → higher intensity**

We suspect, and need more work to test, that …

- **Stronger convective heating**
- **higher firebrand production (source)**
- **farther spotting distances (observation suggests this is true)**
- **Increased firebrand success -- crown fuel ignitions**

Overview

1. **Modeling 101**
    - **Empirical vs. mechanistic models**
2. ***Operational fire models***
    - **limitations in MPB fuels**
3. ***Dynamic fire models***
    - ***Getting under the hood on how fires burn***
4. **MPB & fire: a complex problem**
    - **Immediate (single point in time)**
    - **Fuel changes over time**
5. ***Conclusions***

Modeling 101

What are models?

- **A representation of something**

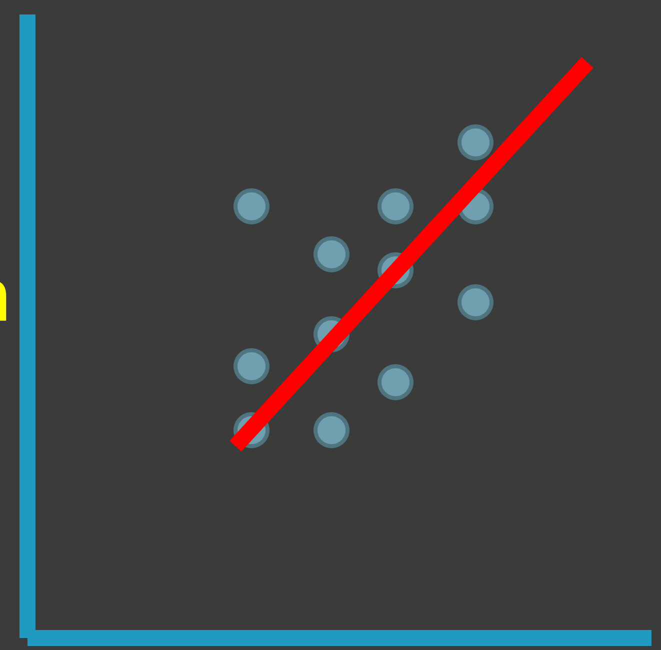
An abstraction

Scale model of a castle

Models in science

“Out of data range”

- Describe or explain relationships
- Often used to predict outcomes
- “what if” scenarios



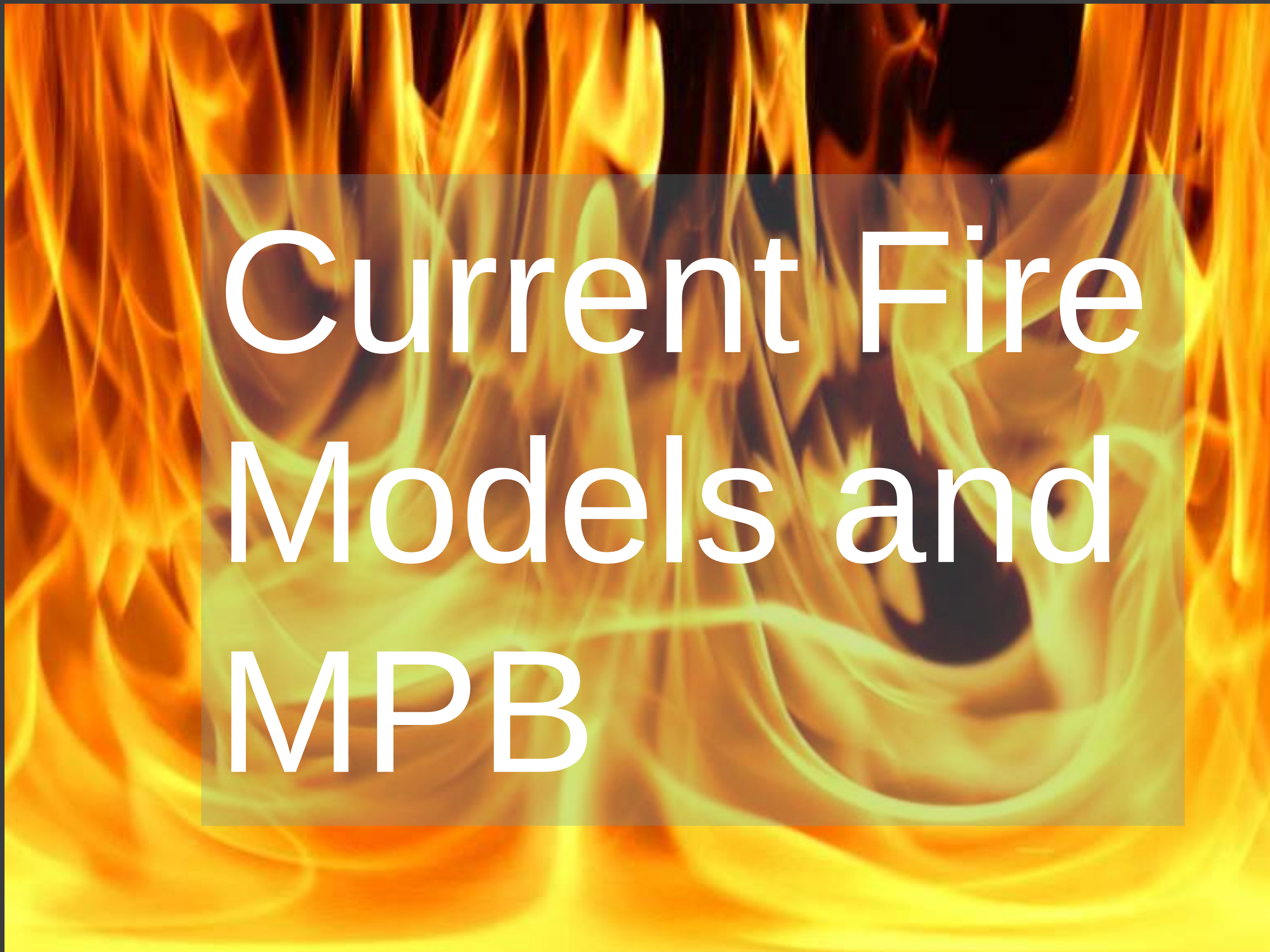
Broad classes of models:

Empirical – based on observation or experiments

Mechanistic / Process – attempt to explain **how** things work

What are Fire Models?

- Computer programs which calculate how fires are expected to burn under particular weather conditions


Current Fire Models and MPB

Uses of modeling in fire management

Planning (strategic)

1. Resource allocation / staffing / status
2. Evaluation of alternative actions (Legal -- NEPA – EIS/EA)
3. Risk and hazard analysis

Operational (tactical)

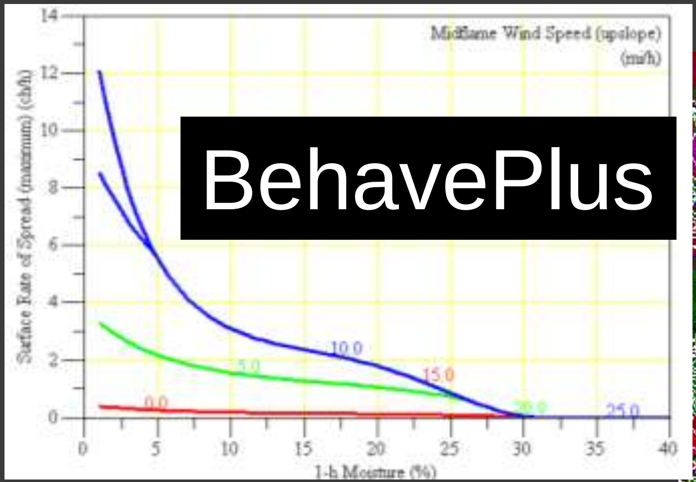
1. Firefighter and community safety
2. When to evacuate?
3. How to fight it?
4. After Action reviews / Legal

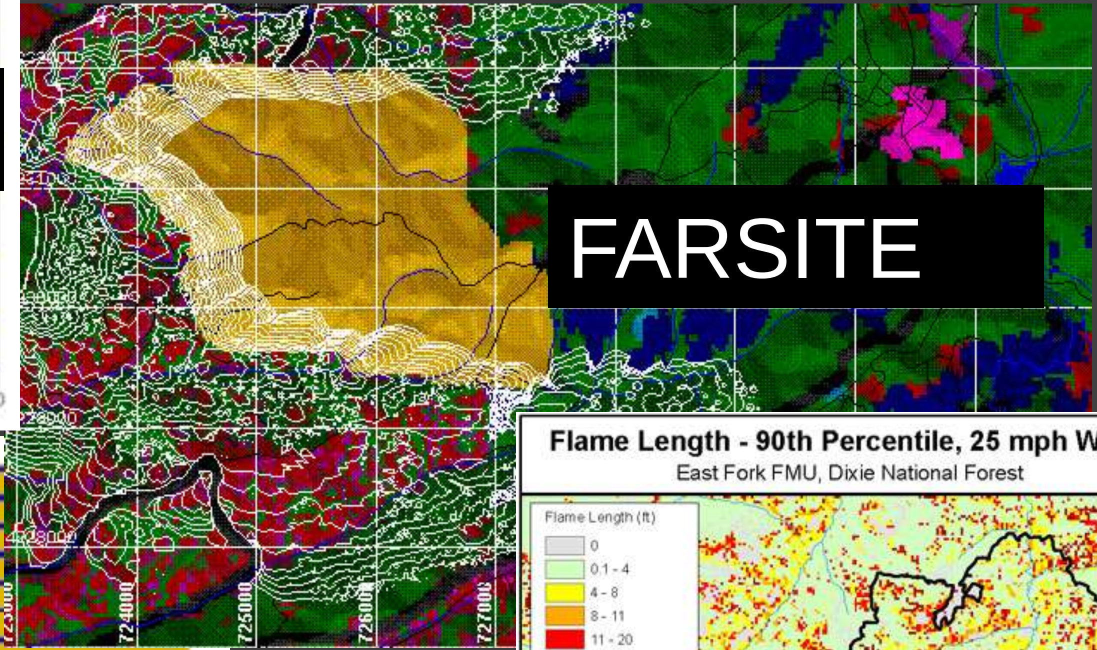
Where we are coming from: modeling fuels and fire behavior

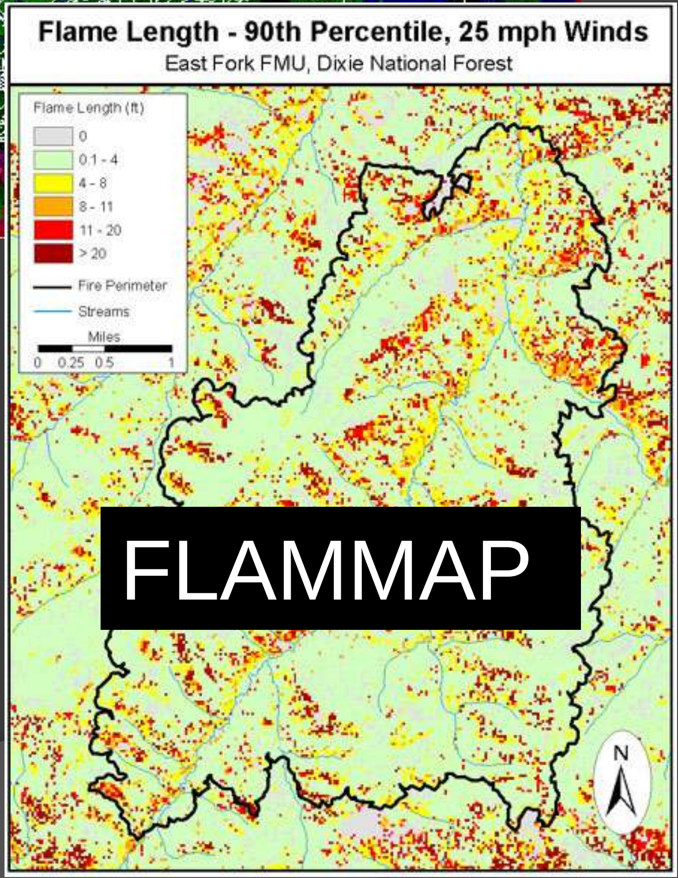
- **Rothermel model 1972**
- semi-empirical: based on laboratory fuel bed burns
- quick calculations: faster than real time
- **<u>Simplifying assumptions:</u>** fuels are homogeneous & continuous
- Quasi-steady state spread
- Mechanisms of heat transfer not explicitly addressed

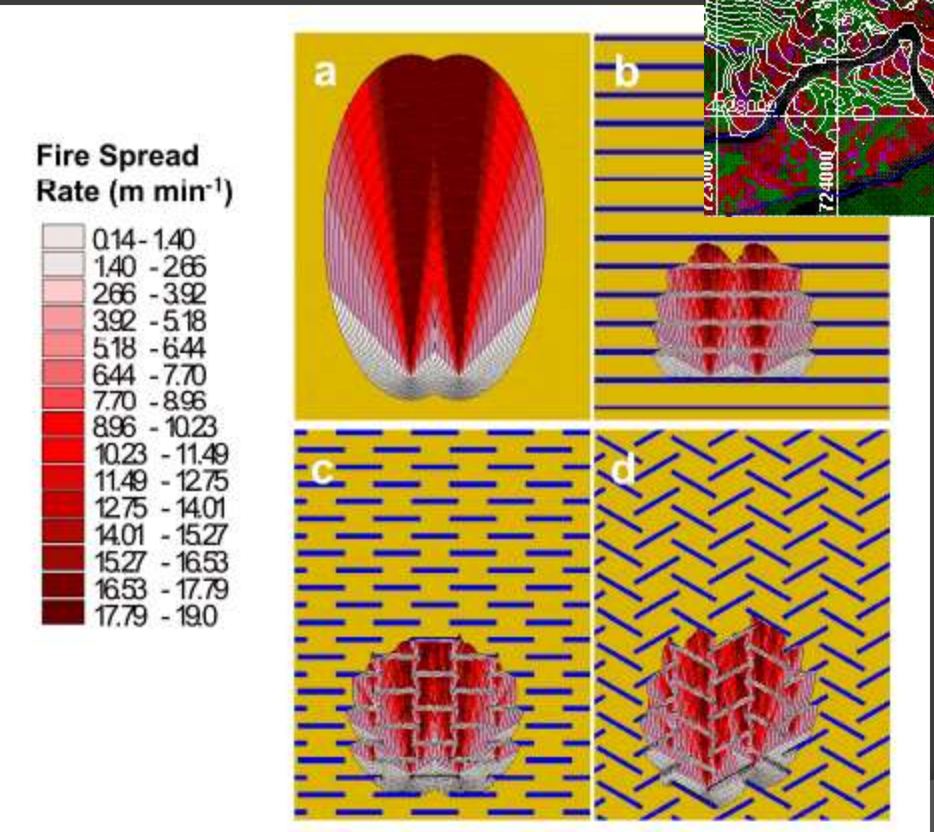
Laboratory test burn

Operational models





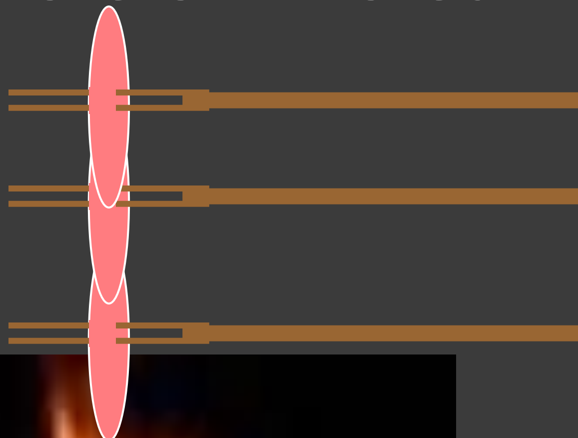


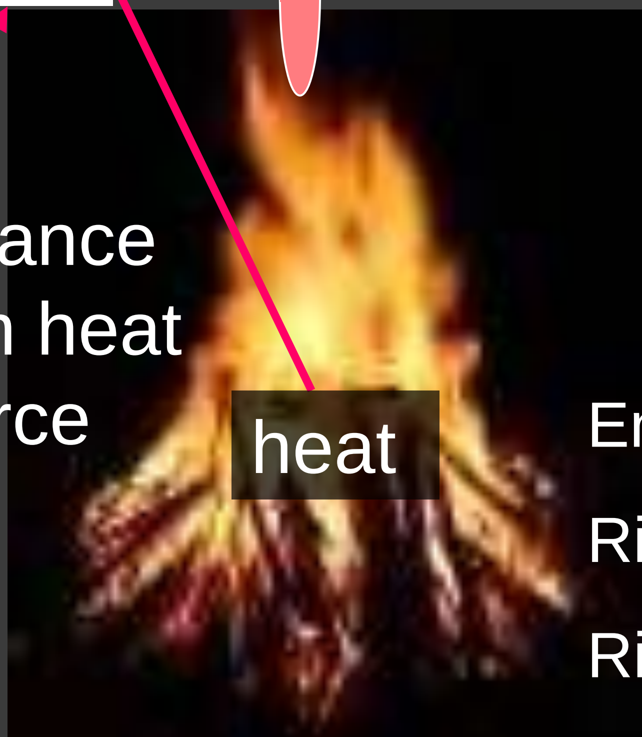


The spatial nature of fire

SA/V

$$q = \frac{\sigma\tau^4}{r^2}$$





Distance from heat source

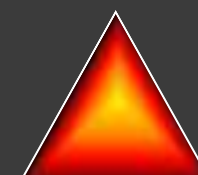
Will it burn?

Enough?

Right size?

Right spacing?

fuel



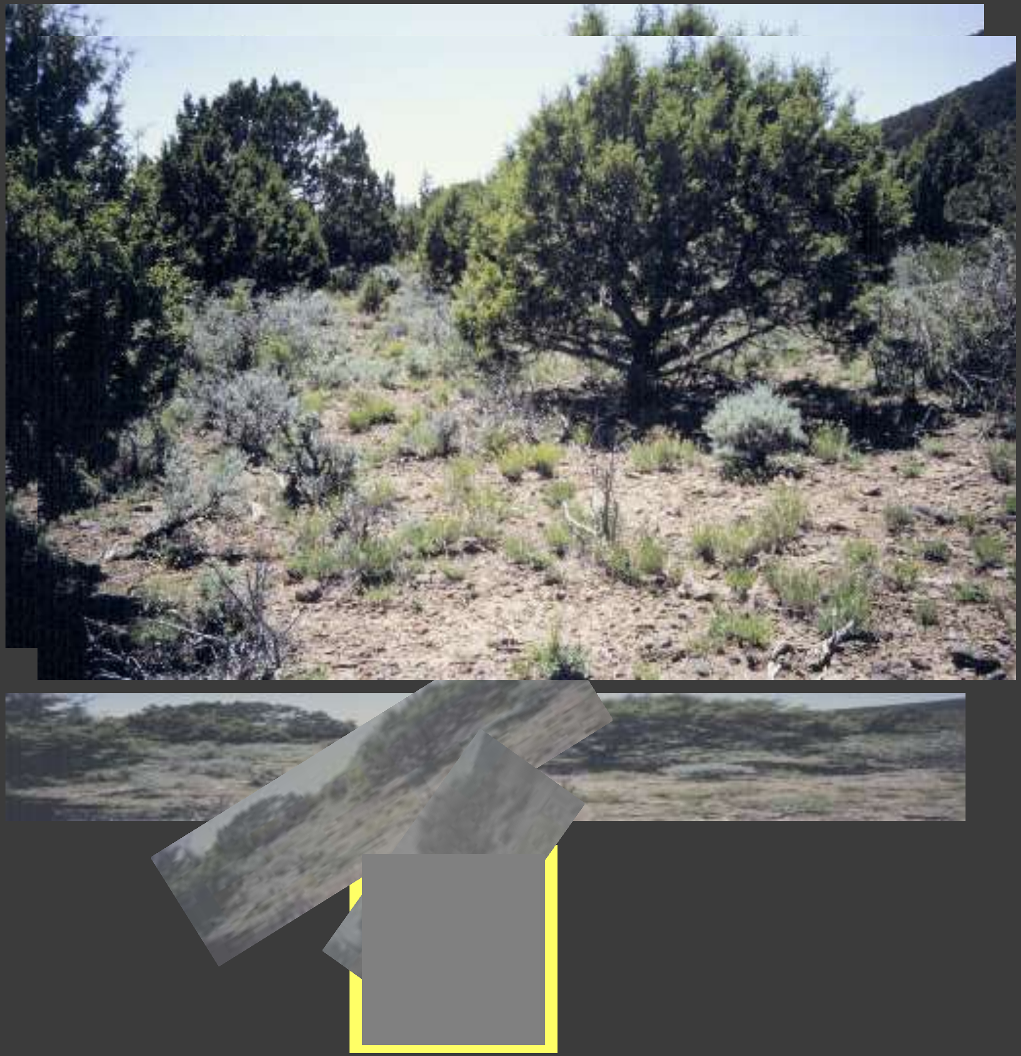
Radiative heat flux

Inconvenient truths about wildland fuels:

Not continuous:
Clumpy, with voids

Not homogeneous:
Highly variable in composition, structure and arrangement

Need to be able to describe and quantify fuels better



Missing the boat?

- How well does a single number really describe wildland fuels?
- At what scale is this simplified fuel description appropriate?
- How do we know?

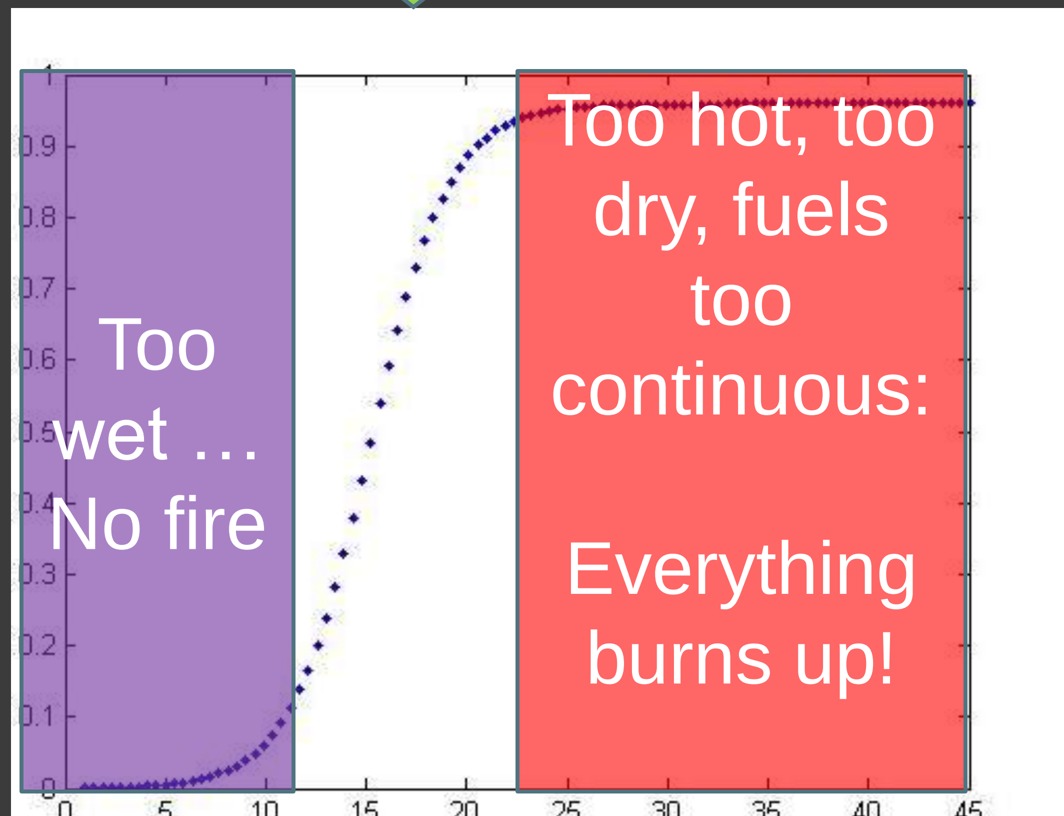
Surface fire

Crown fire

The Goldilocks Zone

~~Finding thresholds in fire behavior~~

Probability of crown fire



Environmental / fuel conditions

Fire behavior in the “Goldilocks zone”

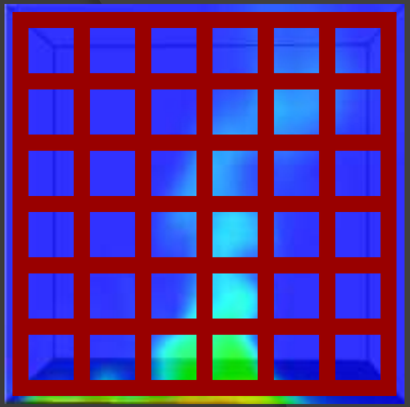
- Subtle changes in conditions lead to large changes in fire behavior
- Very conditional, in transition: dynamic
- Operational models do NOT give reliable answers here!
- New approaches are needed

Limitations of current models in beetle-kill stands

- Don’t capture fuel heterogeneity – e.g. % of trees bug killed
- No within-stand spatial aspects
- Models can’t handle standing dead foliage
- Not reliable for transition to crown fire
- Don’t address changes in spotting (either source or target)
- Couplings can produce rapid changes – not addressed by current models
- Do not adequately characterize potential threats to firefighter safety

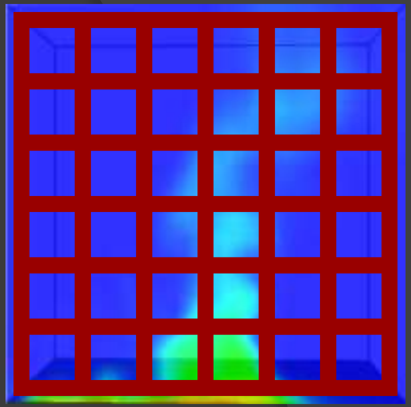

Dynamic
Fire
Modeling

Dynamic fire models



- Finer scale: many small cells, 3D
- Mechanistic: robust physics
- “Coupled”: fire-atmosphere, fire-fuels, fuels-atmosphere, topography-atmosphere
- Computationally demanding
- Research emphasis: not yet used in management … BUT
- … have big potential for guiding management.

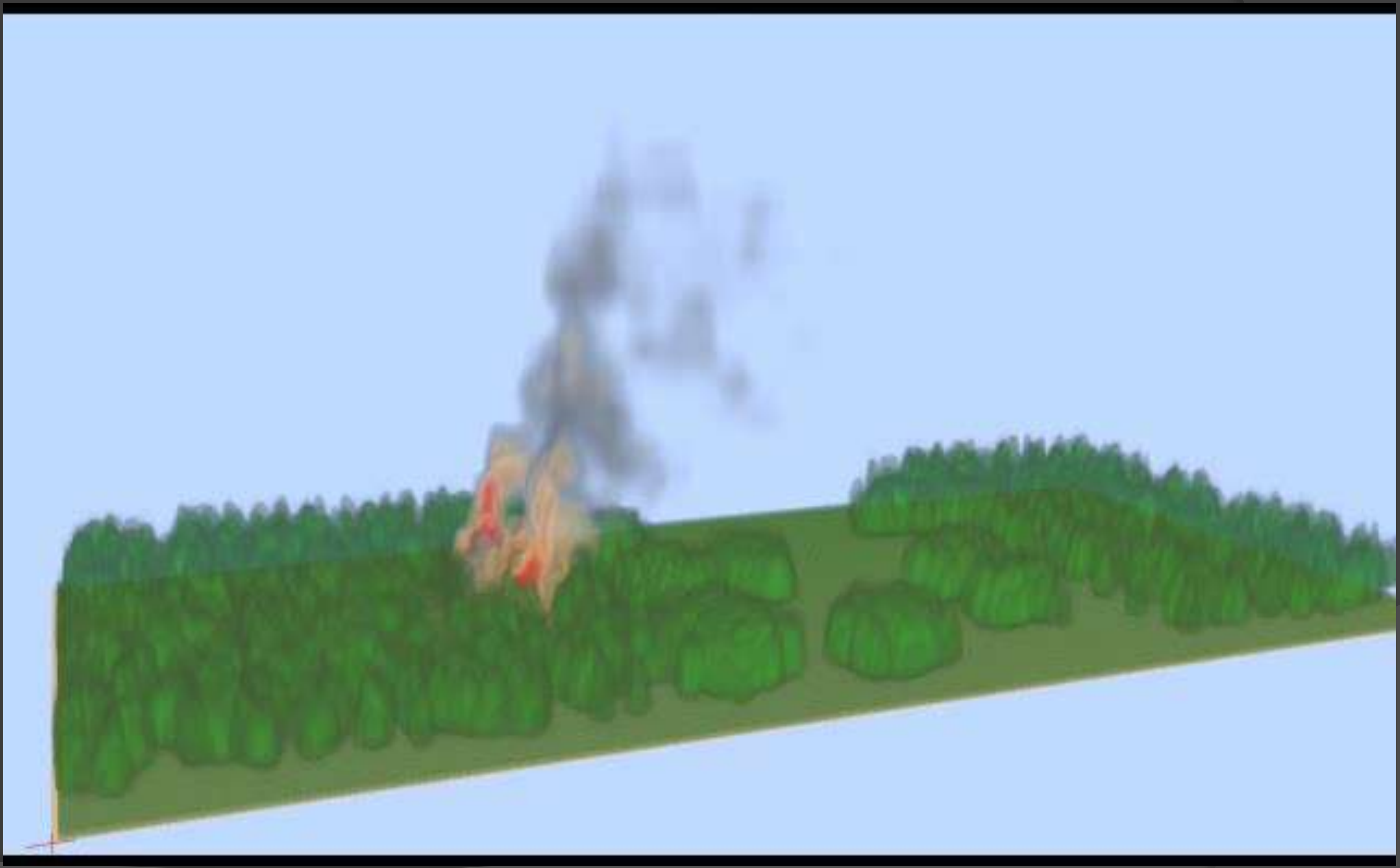
Dynamic fire models



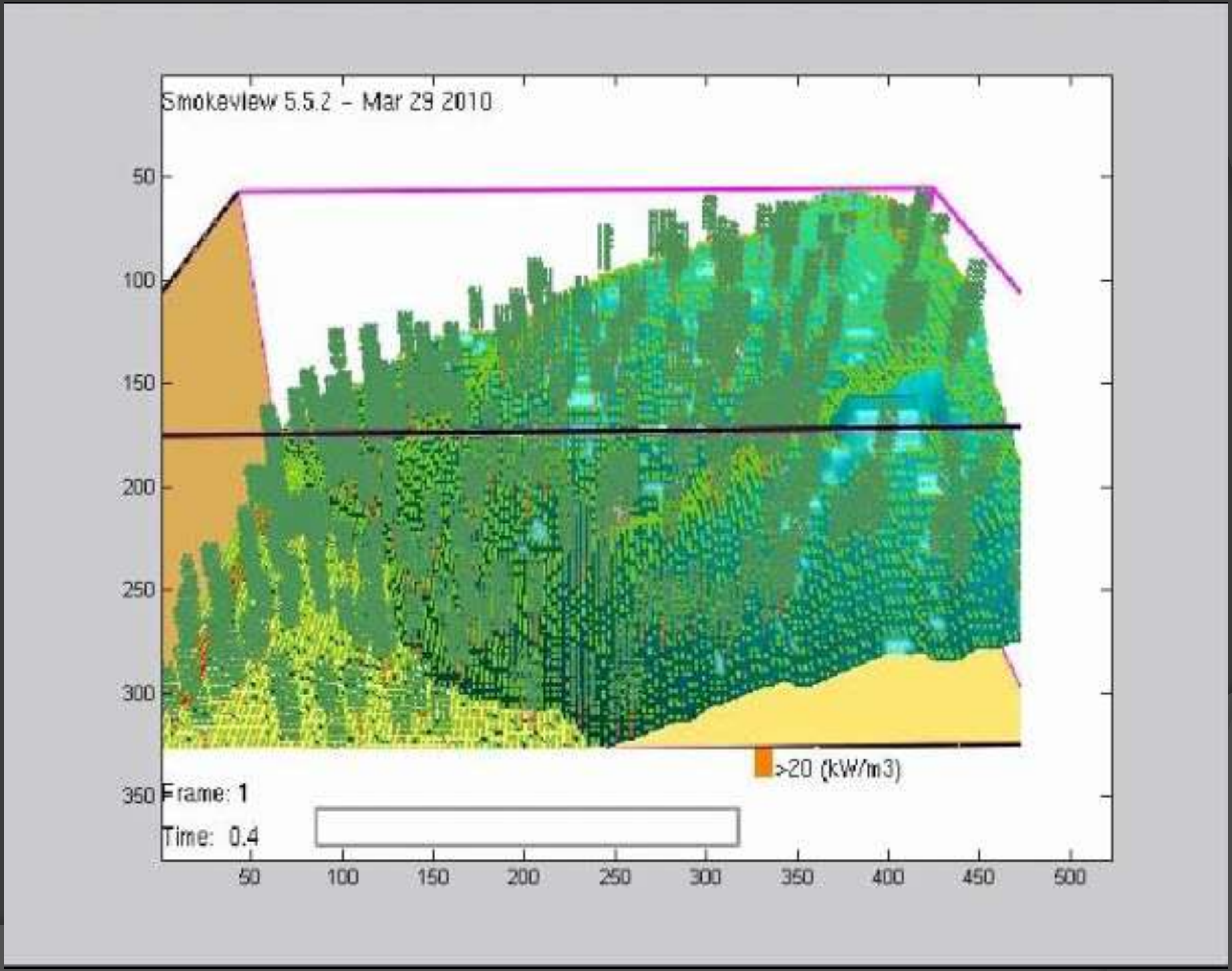
Two main models

- 1) FIRETEC
- Los Alamos National Lab – Rod Linn
- Very strong on wind field, topographic infl.
- 2) Fire Dynamics Simulator (FDS)
- N.I.S.T -- William Mell
- Structure fire origins, adapted for wildland fire

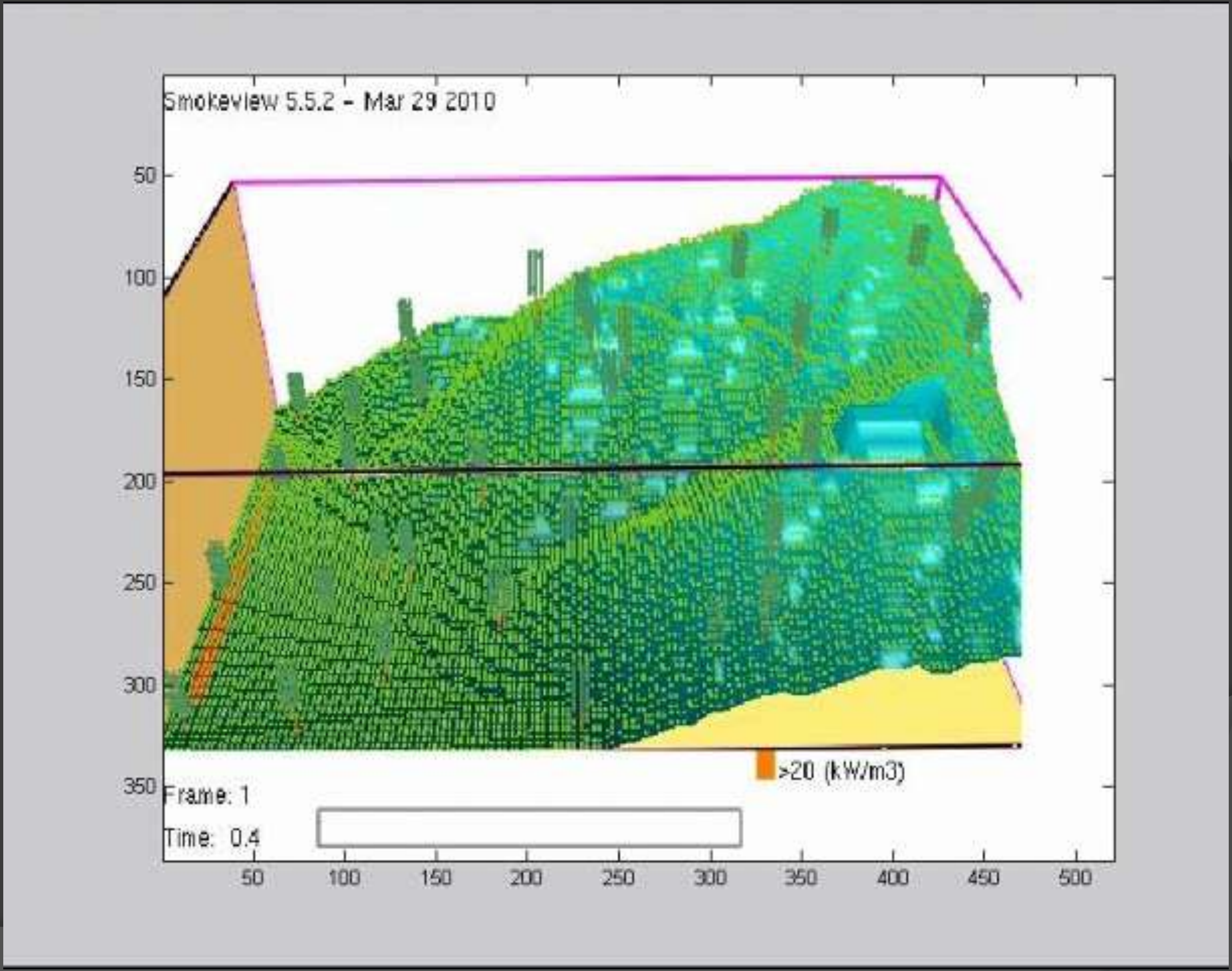
Dynamic Fire Simulation – FIRETEC model



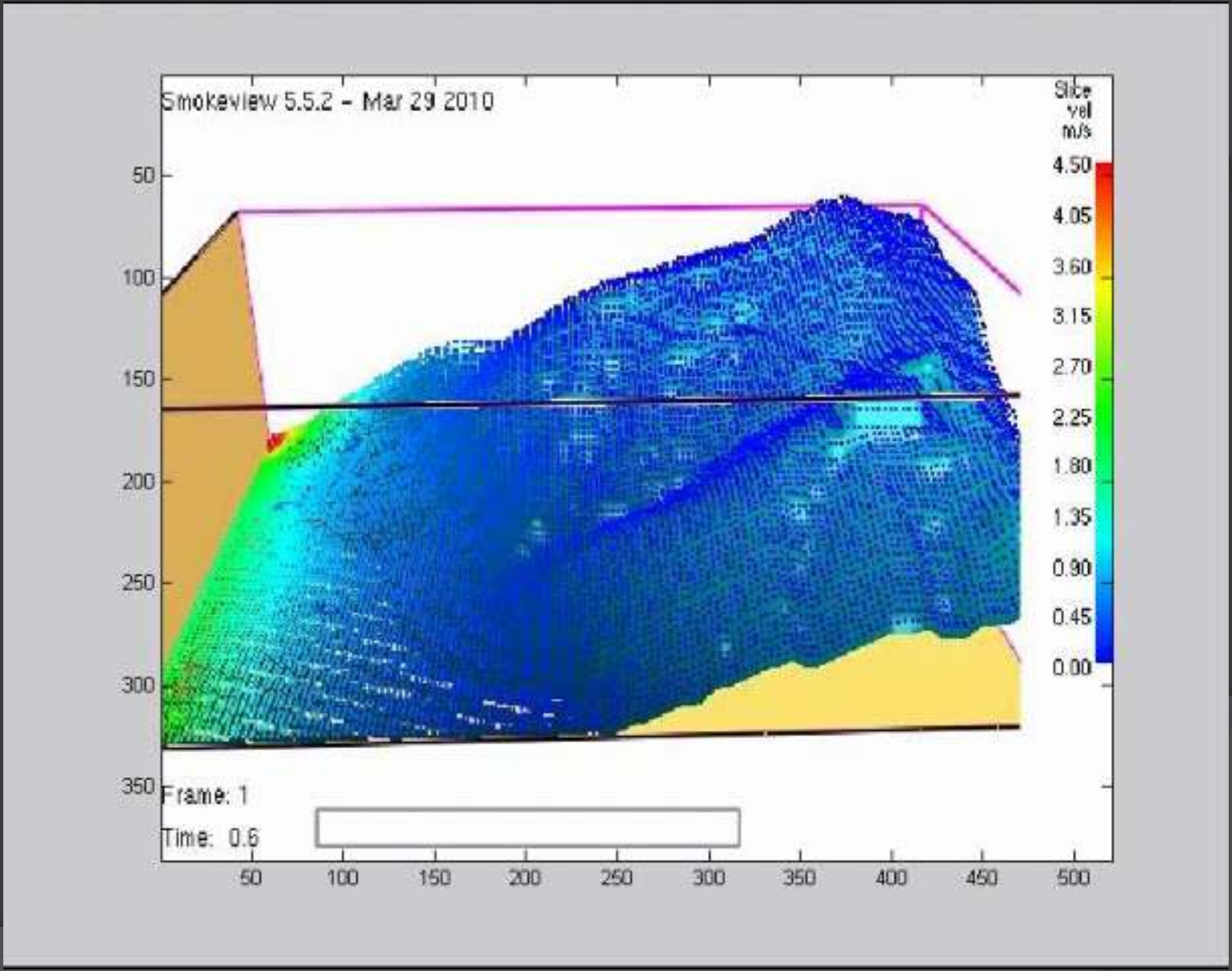
Fire in unthinned stand – FDS model



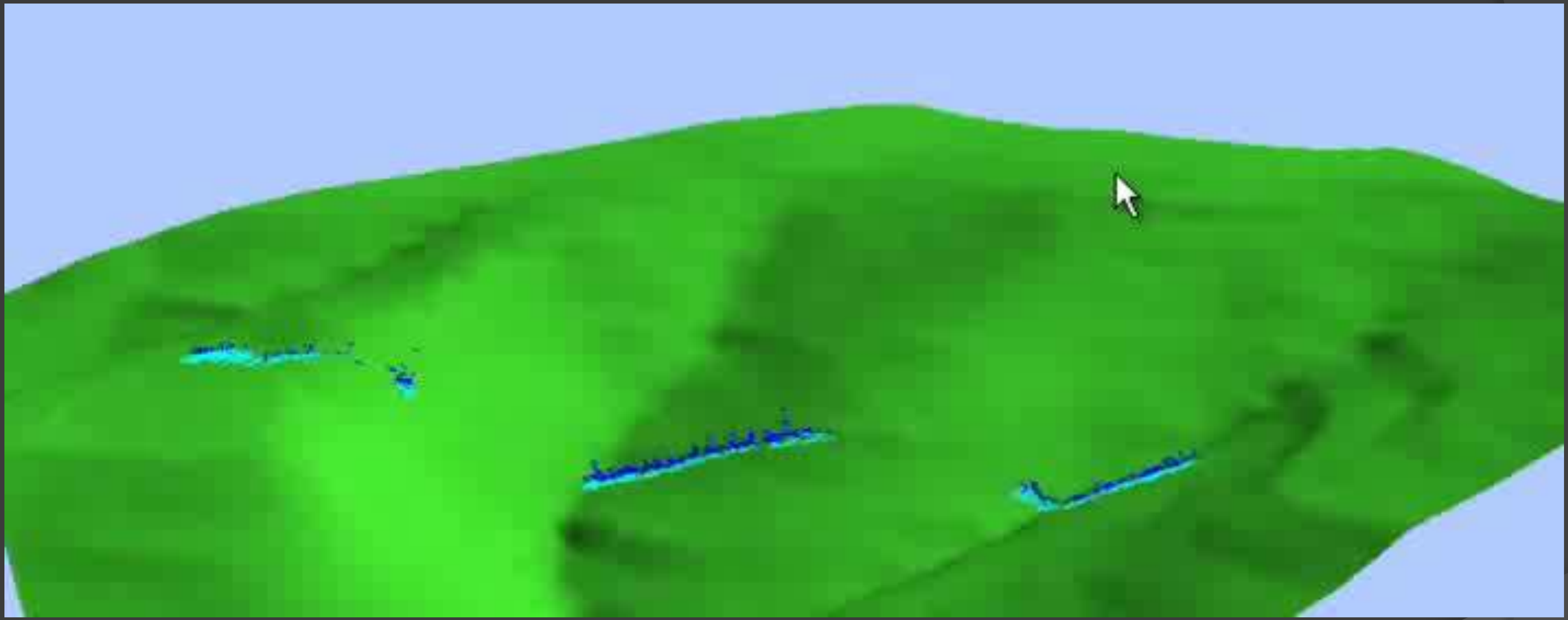
Fire after thinning



Windfield visualization – thinned forest

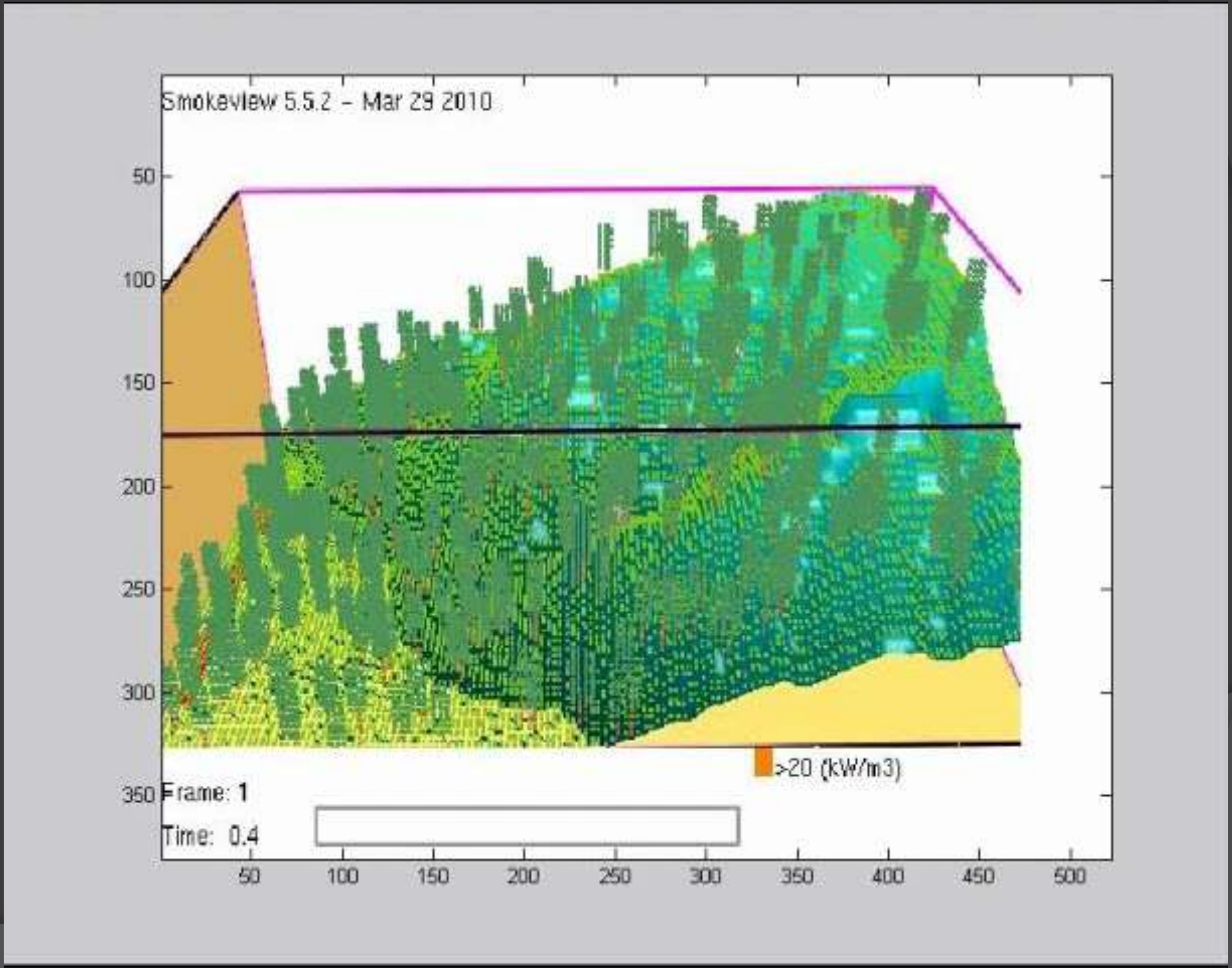


Wind transport of burning embers: a critical component in wildfire spread

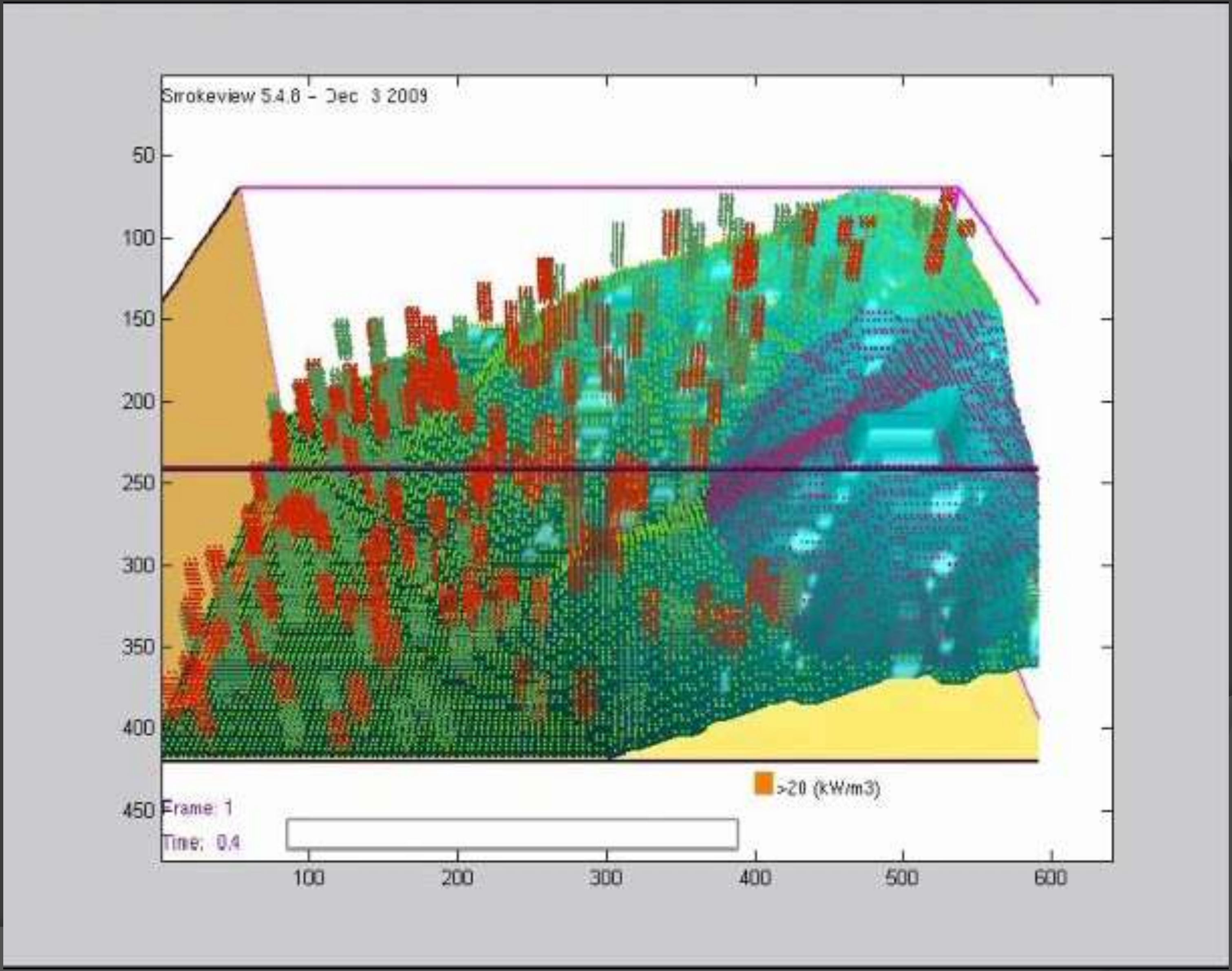


Exploring the Goldilocks zone: MPB fuels and fire behavior thresholds

Fire in unthinned stand – FDS model



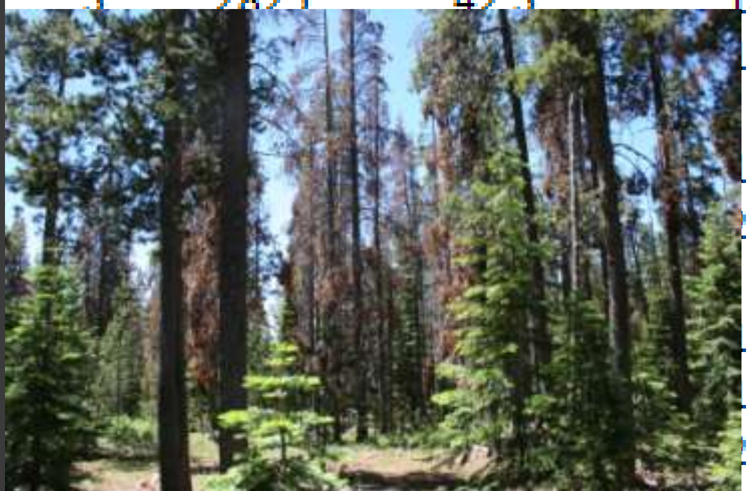
unthinned stand w. 60% bug kill + structure protection

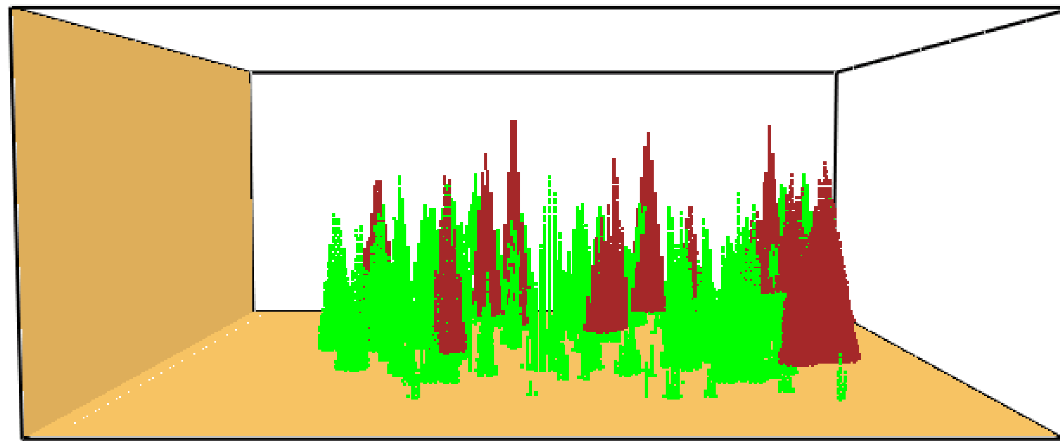


MPB attacks – immediate effects

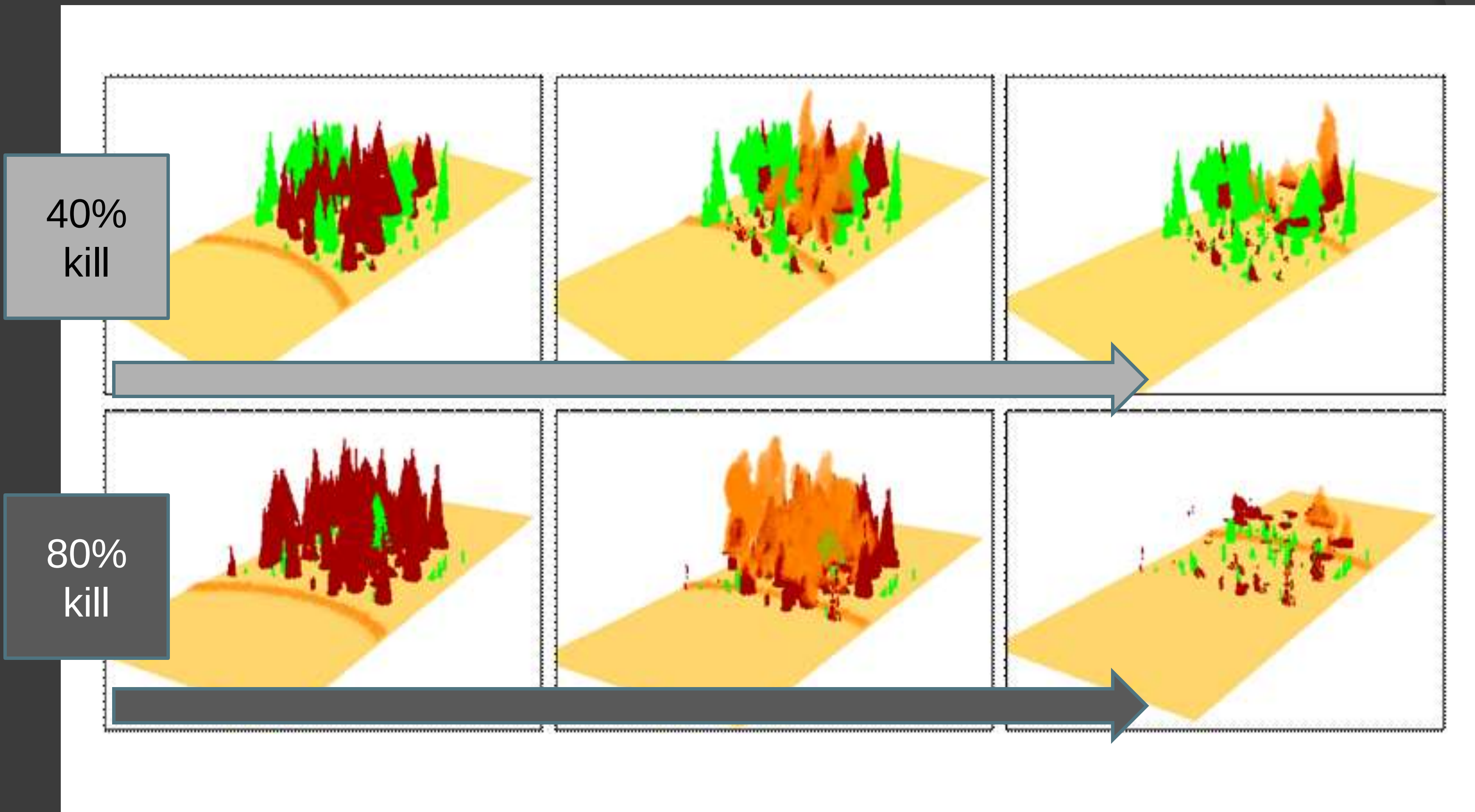
Real Fuels Data – 11 Sites

Site #	Trees ha^{-1}	BA(m^2 ha^{-1})	QMD (cm)	HT(m)	CBH (m)	Species composition*
1	997	26.6	18.2	10.8	3.8	LPP 100%
2	775	28.6	21.4	11.6	3.5	LPP 80%, GF 20%
3	2825	42.3	13.6	9.5	3.7	LPP 100%
10	1112	28.0	17.7	10.5	3.4	LPP 58%, WBP 28%, SF 14%
11	1406	36.5	17.9	14.0	5.8	LPP 60%, DF 31%, ES 6%, SF 2%



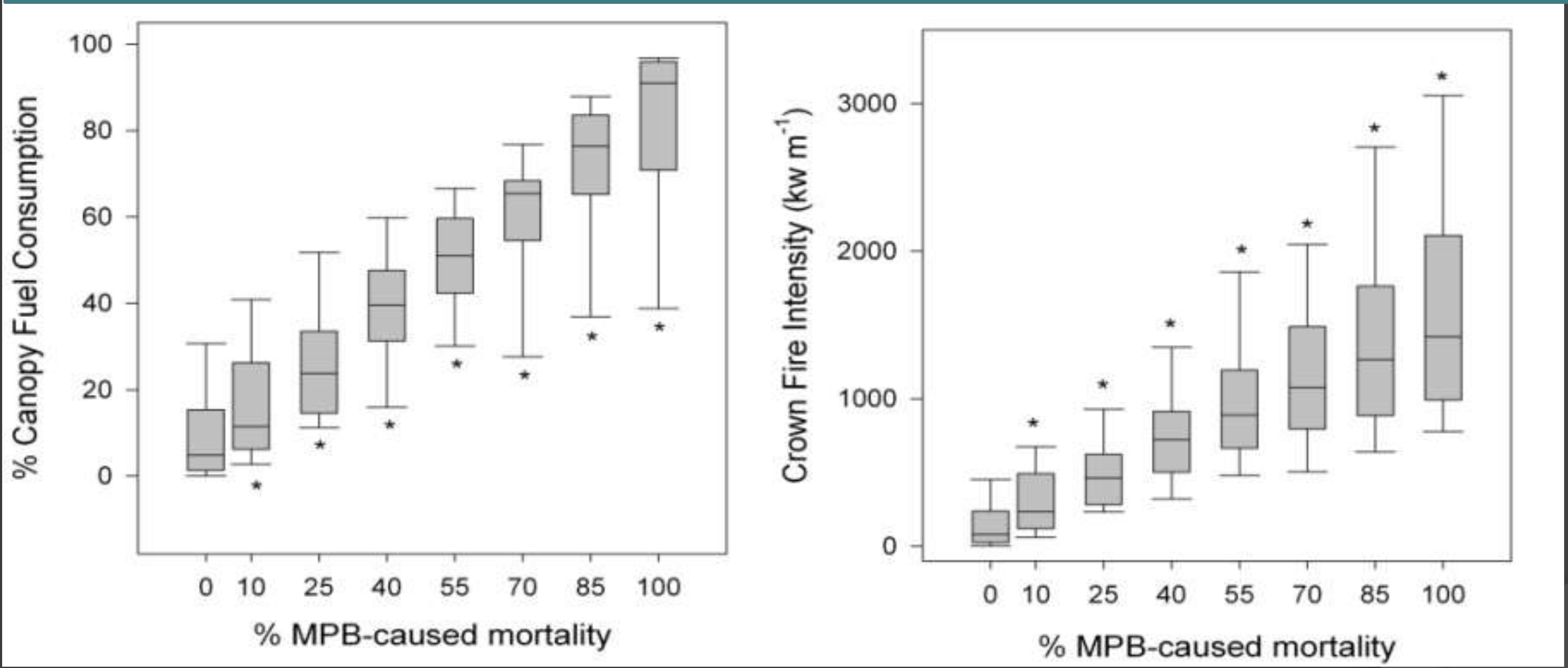


Red stage fire intensity increases with % beetle kill



Results: Red phase

Stand structure differences between sites were also significant but did not have strong effects compared to % kill



Box and whisker plots showing the predicted canopy fuel consumption and crown fire intensity by percent mortality. Box and whisker diagrams labeled with a * are significantly different ($\alpha = 0.05$) from the zero mortality simulation.

MPB attacks – over time

Vegetation and avian community response to a mountain pine beetle epidemic in the Elkhorn Mts, Helena NF

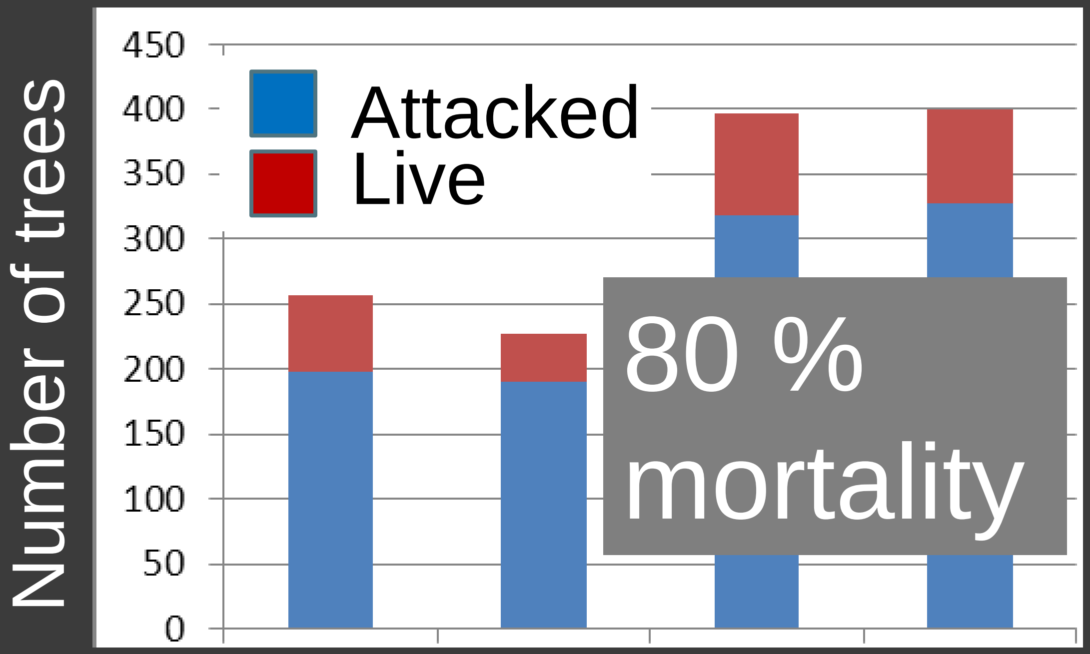
Brittany Mosher & Victoria Saab

2006

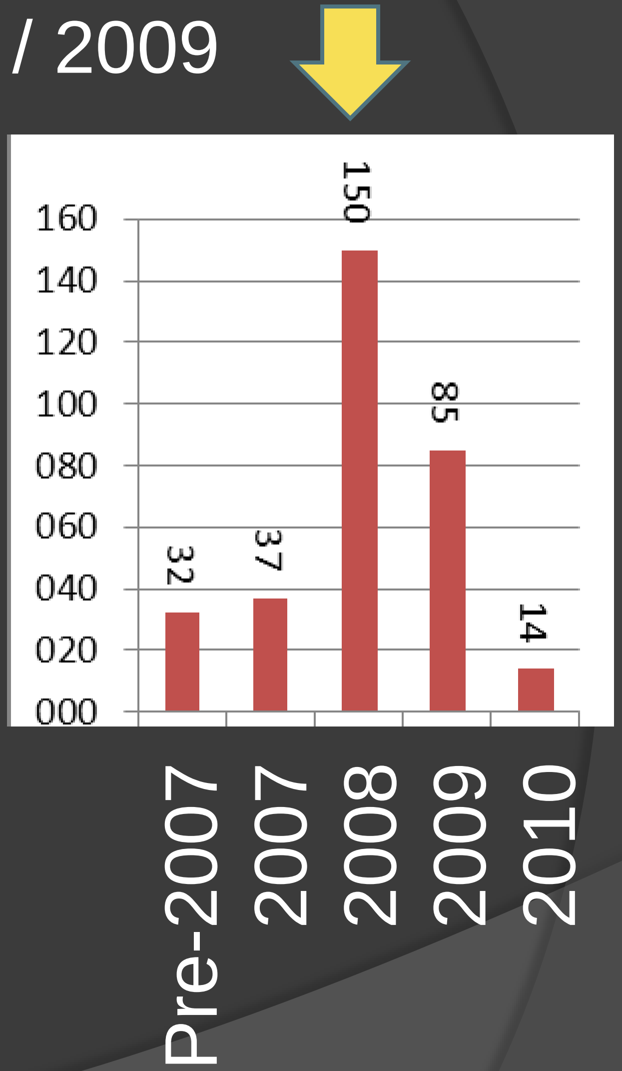
2009

MPB attack – over time

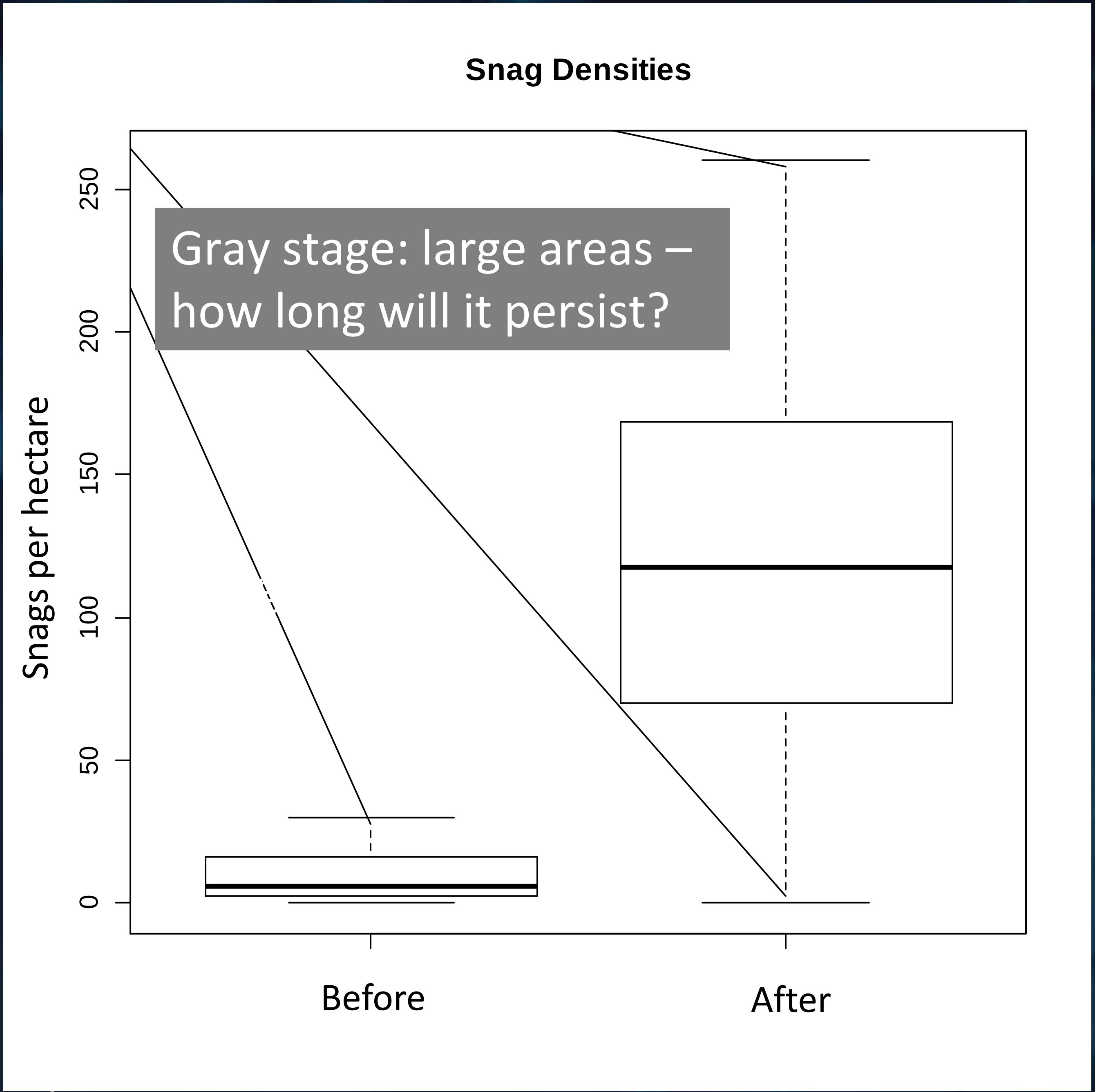
Peak trees killed in 2008 / 2009



4 Different areas



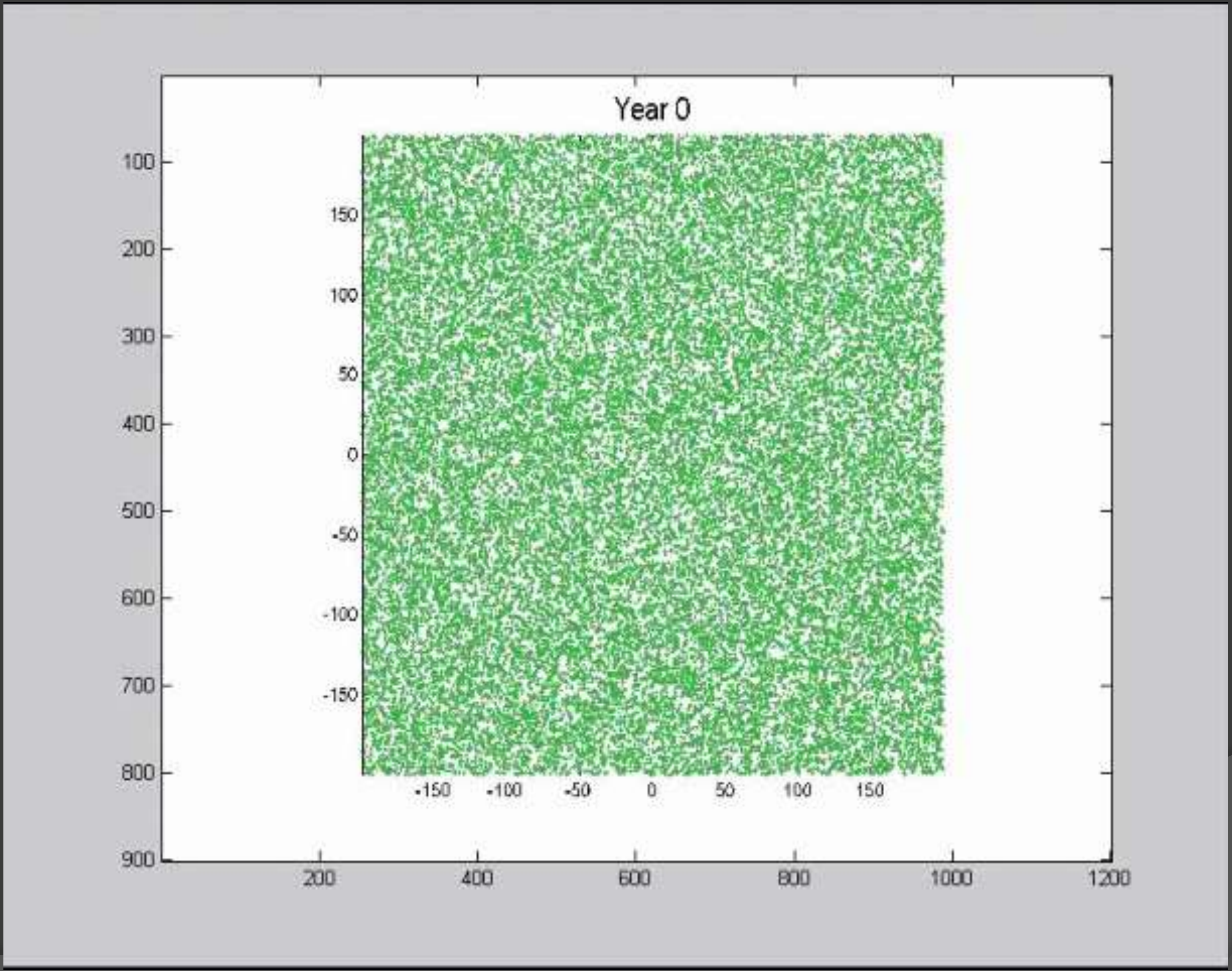
Mountain pine beetle (MPB) survey -- Elkhorn Wildlife Management Unit, Helena National Forest. Data collected August 24-27, 2010. Joel Martin & Barbara Bentz.


Snag Densities
Gray stage: large areas –
how long will it persist?
Snags per hectare
0
50
100
150
200
250
Before
After

Saab & Mosher

Simulating Beetle kill spread: tree to tree

Low and slow mortality pulse



Simulating Beetle kill spread: tree to tree

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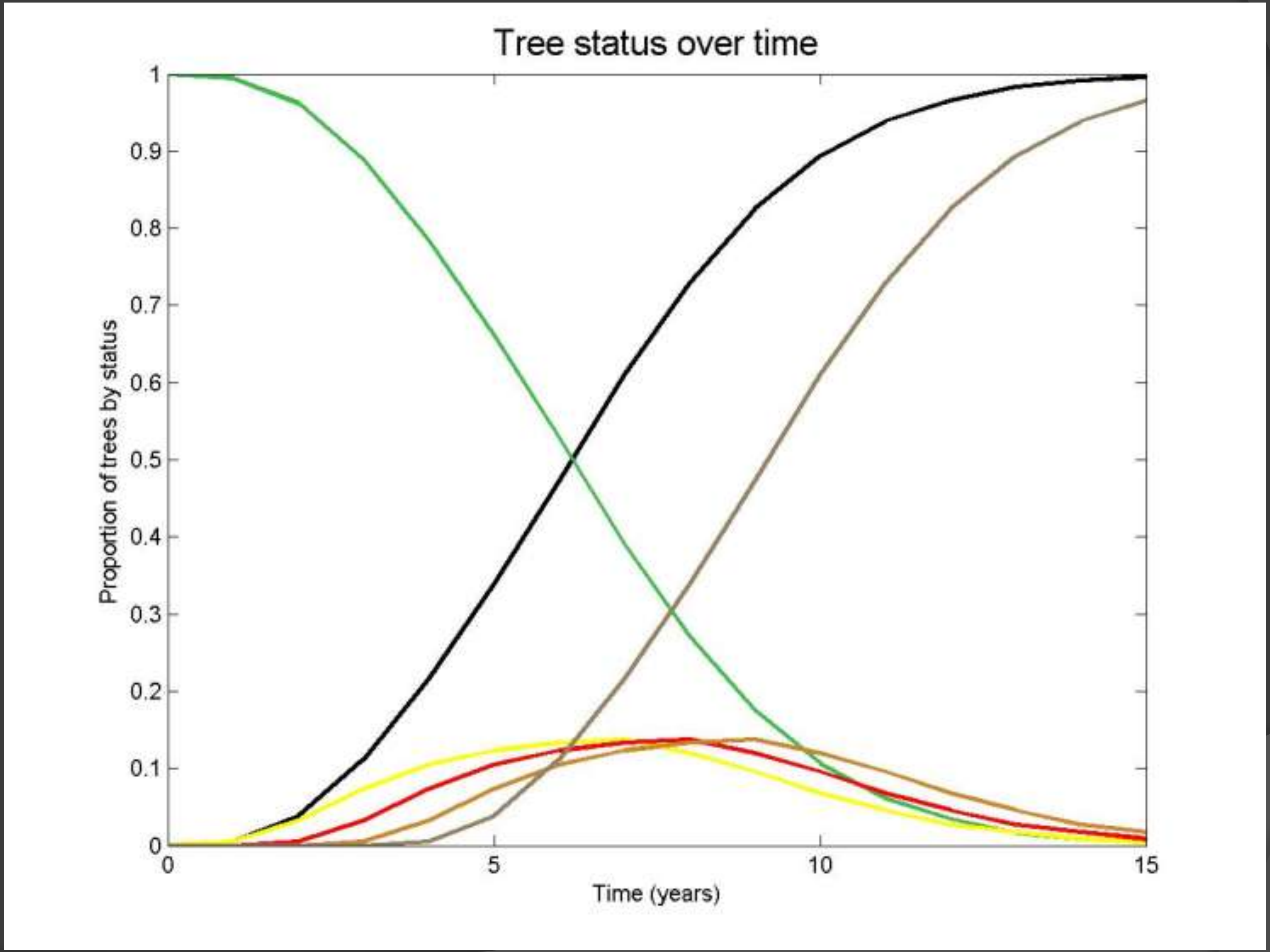
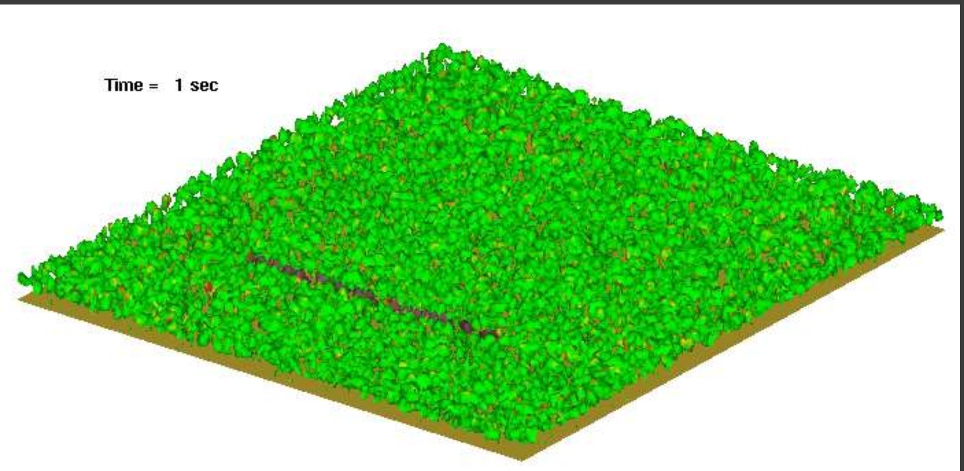
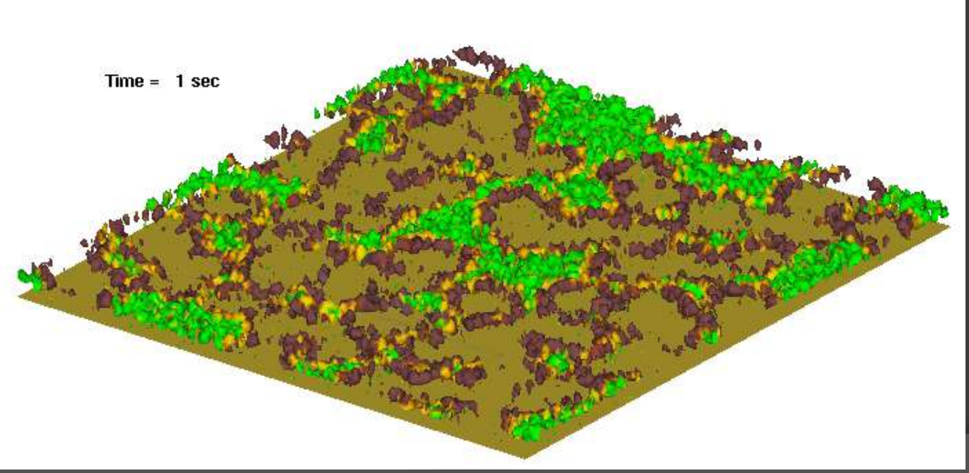


Low and Slow mortality pulse

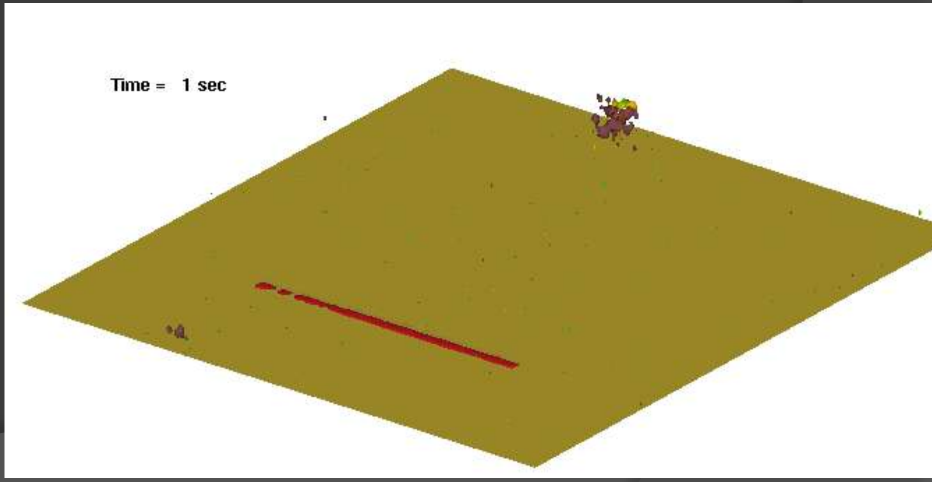


Before attack

4 yr. post attack



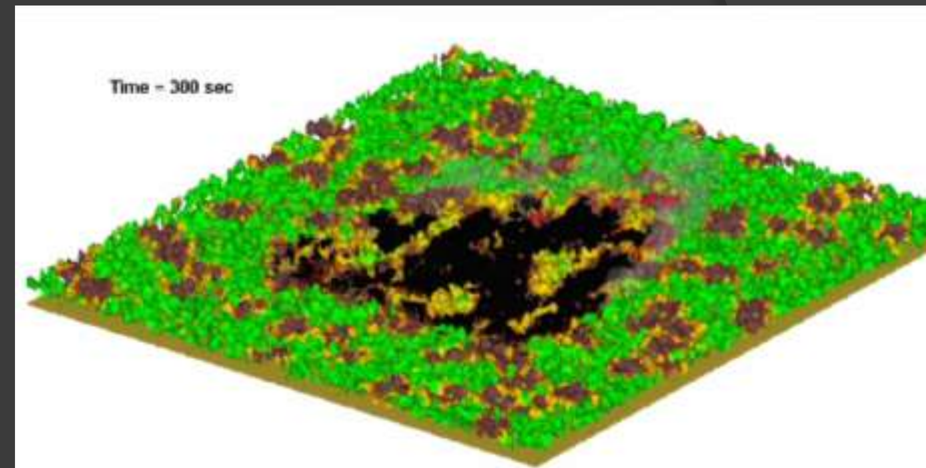
7 yr. post attack



15 yr. post attack

Low and Slow mortality pulse

Before attack



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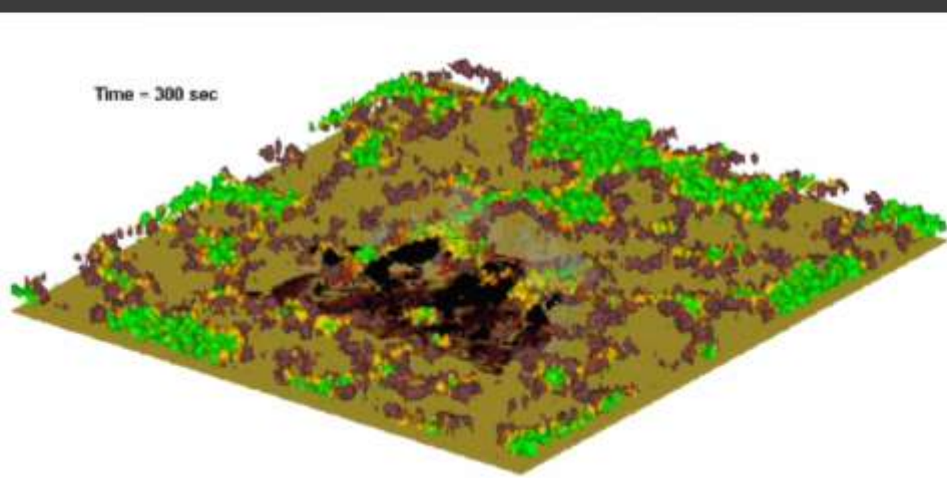

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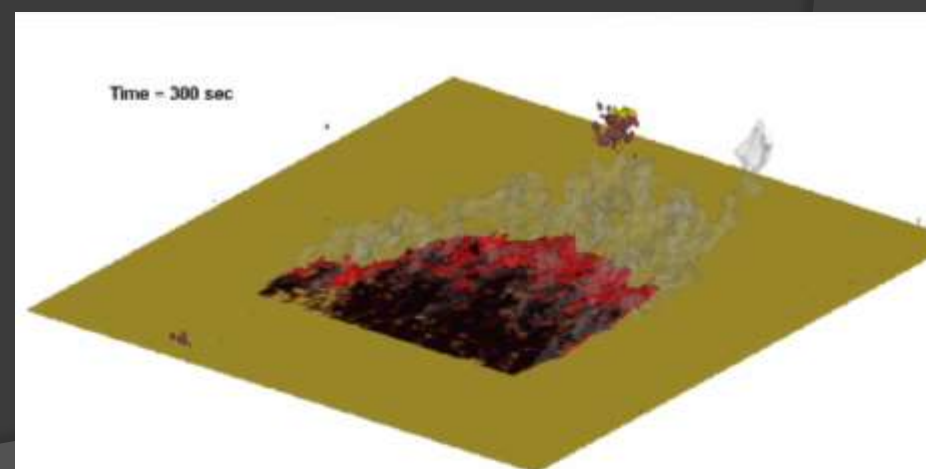
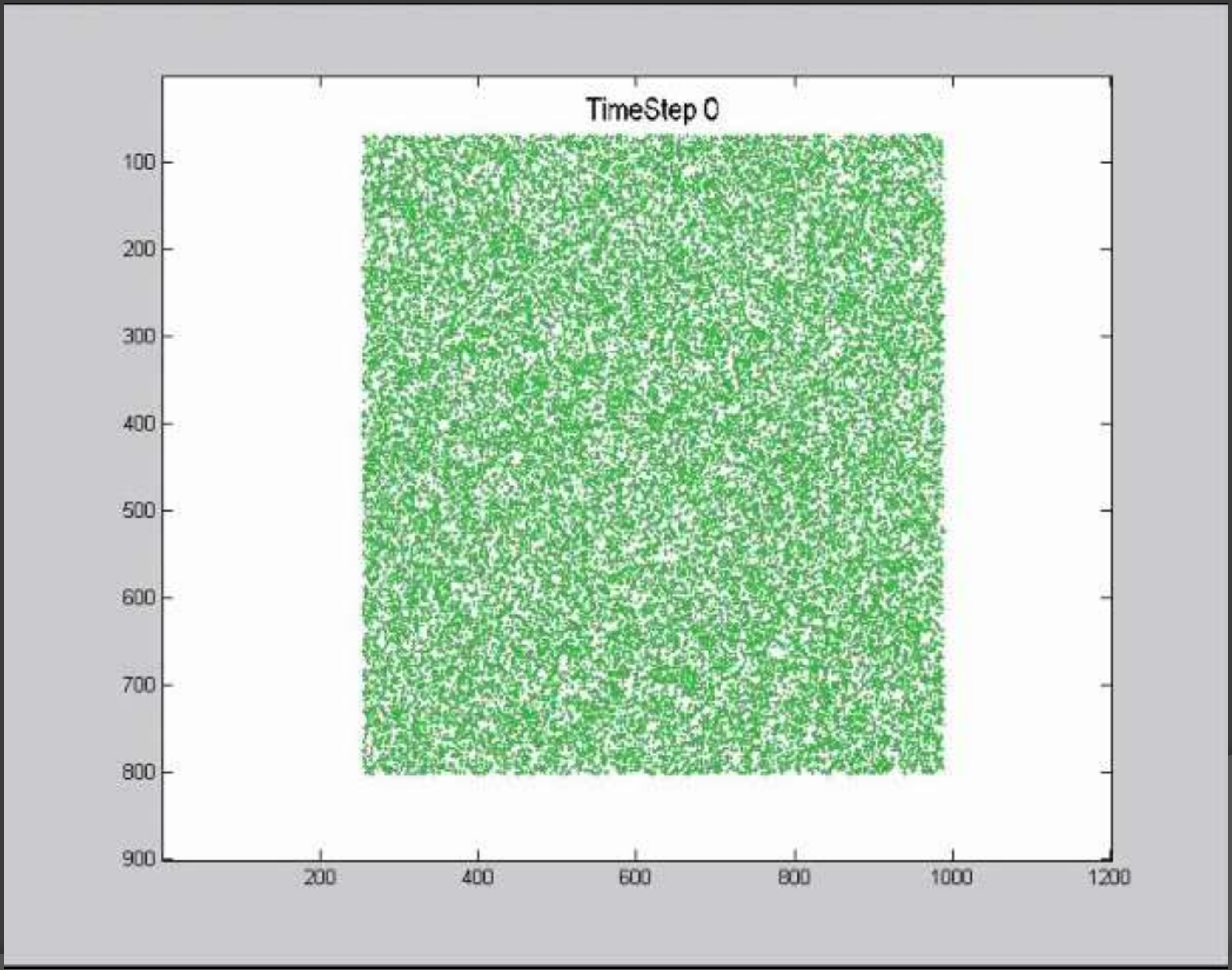


15 yr. post attack

Simulating Beetle kill spread: tree to tree

High and fast mortality pulse



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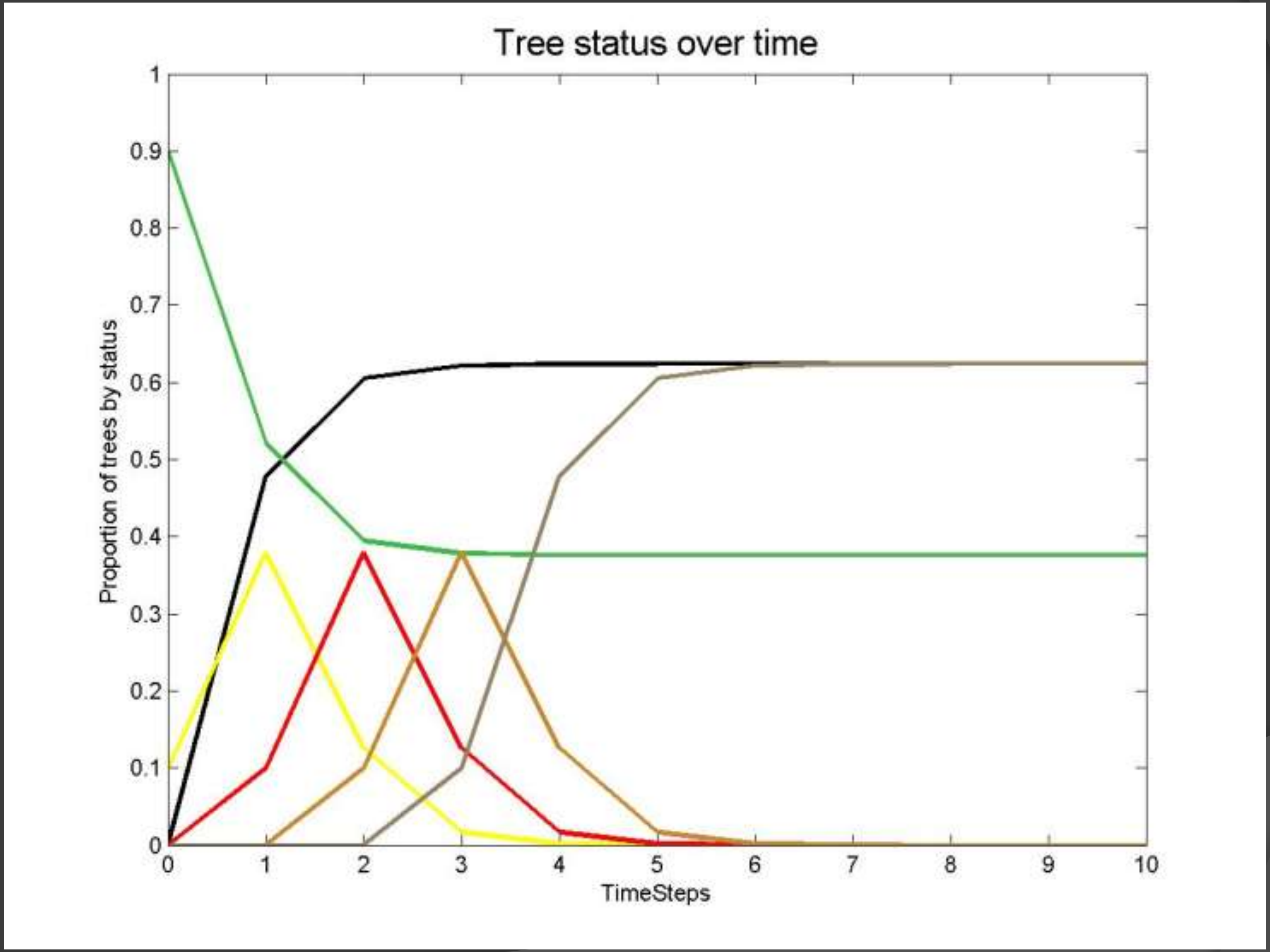
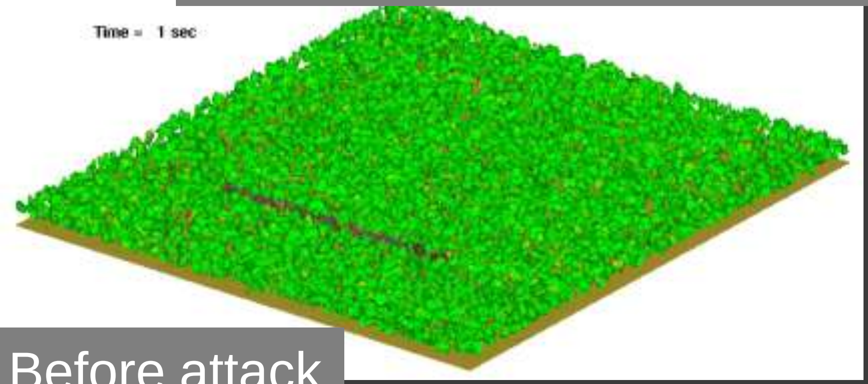
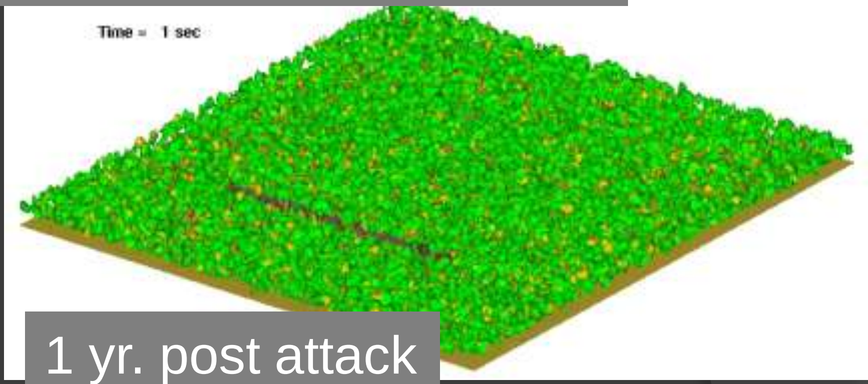


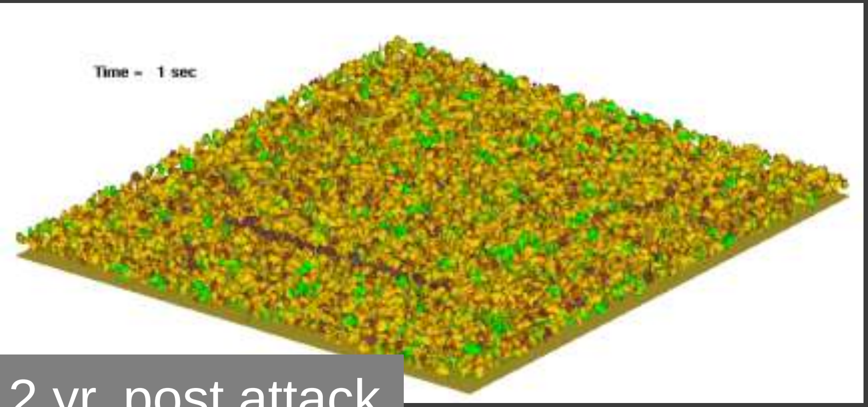
High and Fast Mortality Pulse



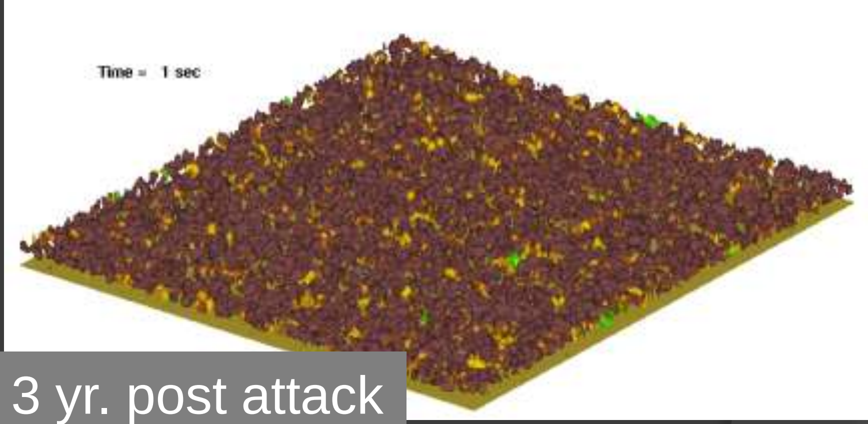
Before attack



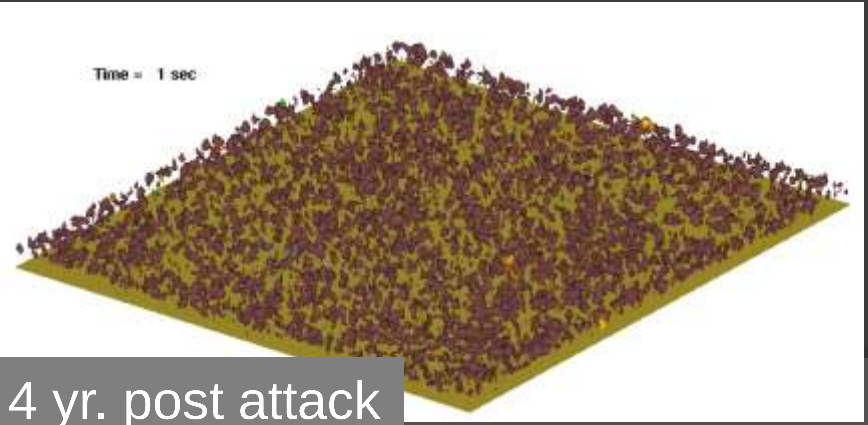
1 yr. post attack



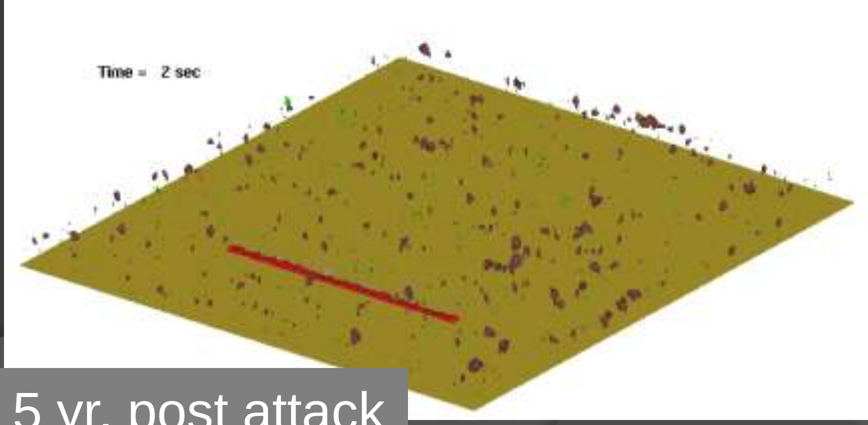
2 yr. post attack



3 yr. post attack

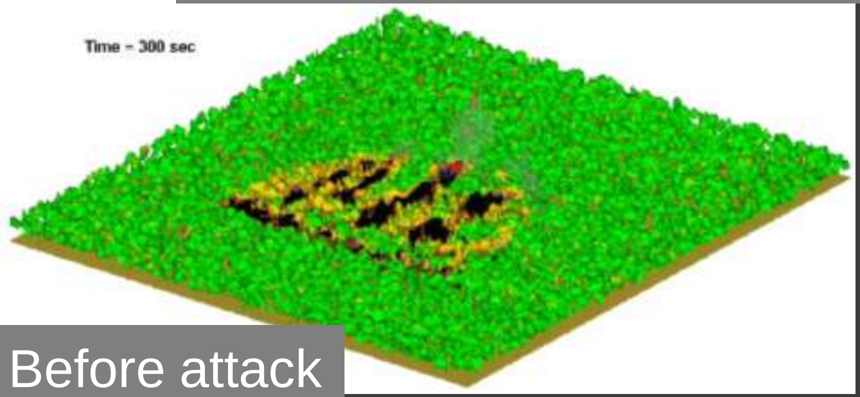


4 yr. post attack

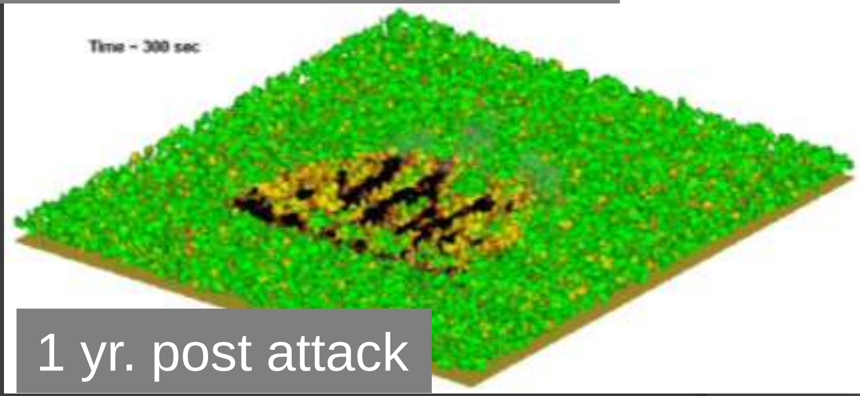


5 yr. post attack

High and Fast Mortality Pulse



Before attack



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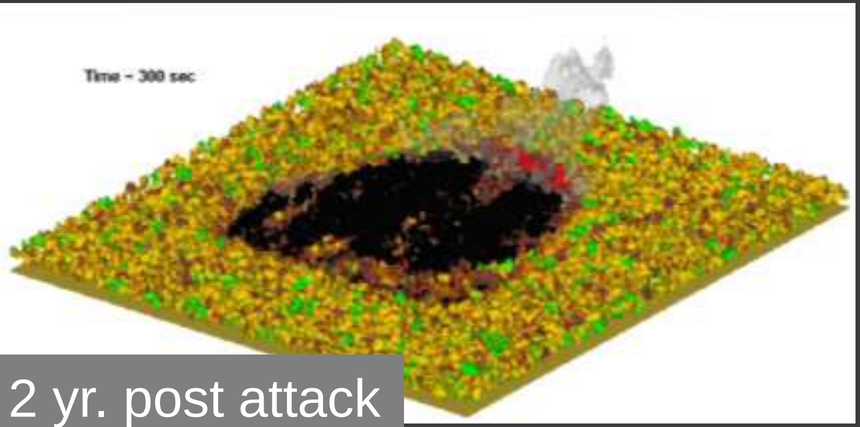
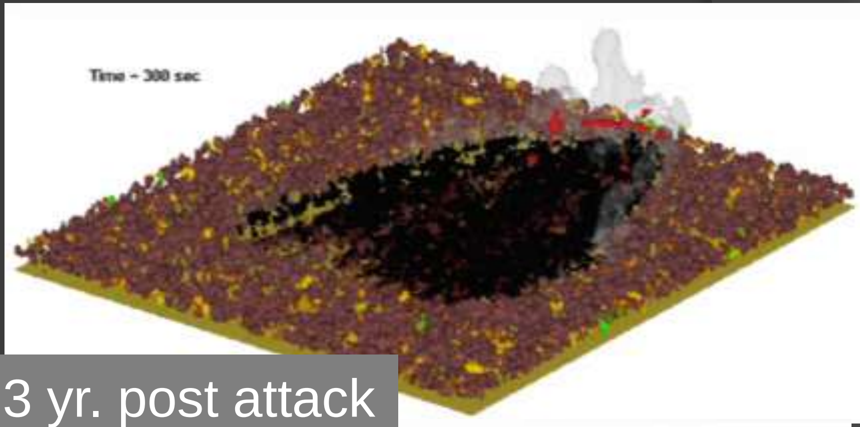


2 yr. post attack



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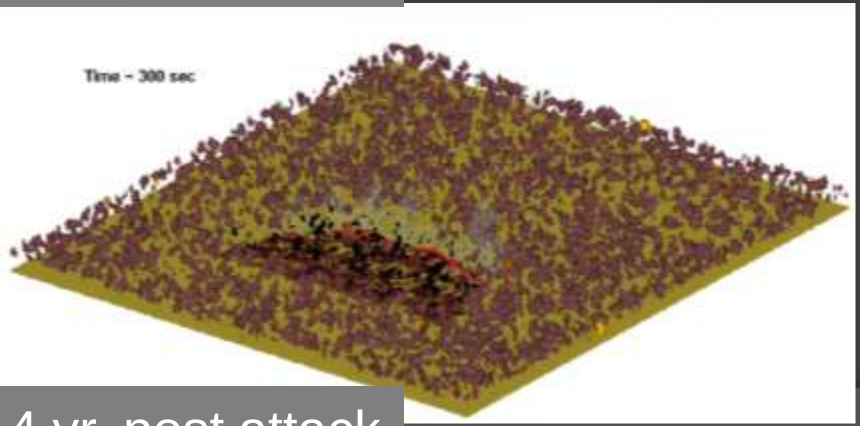
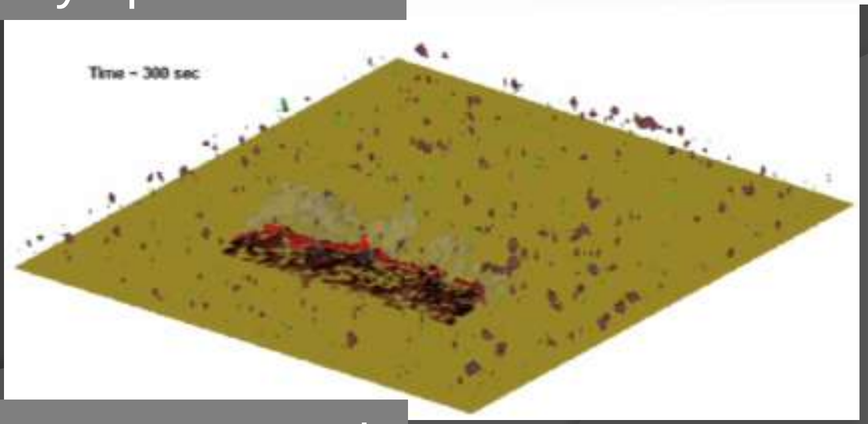
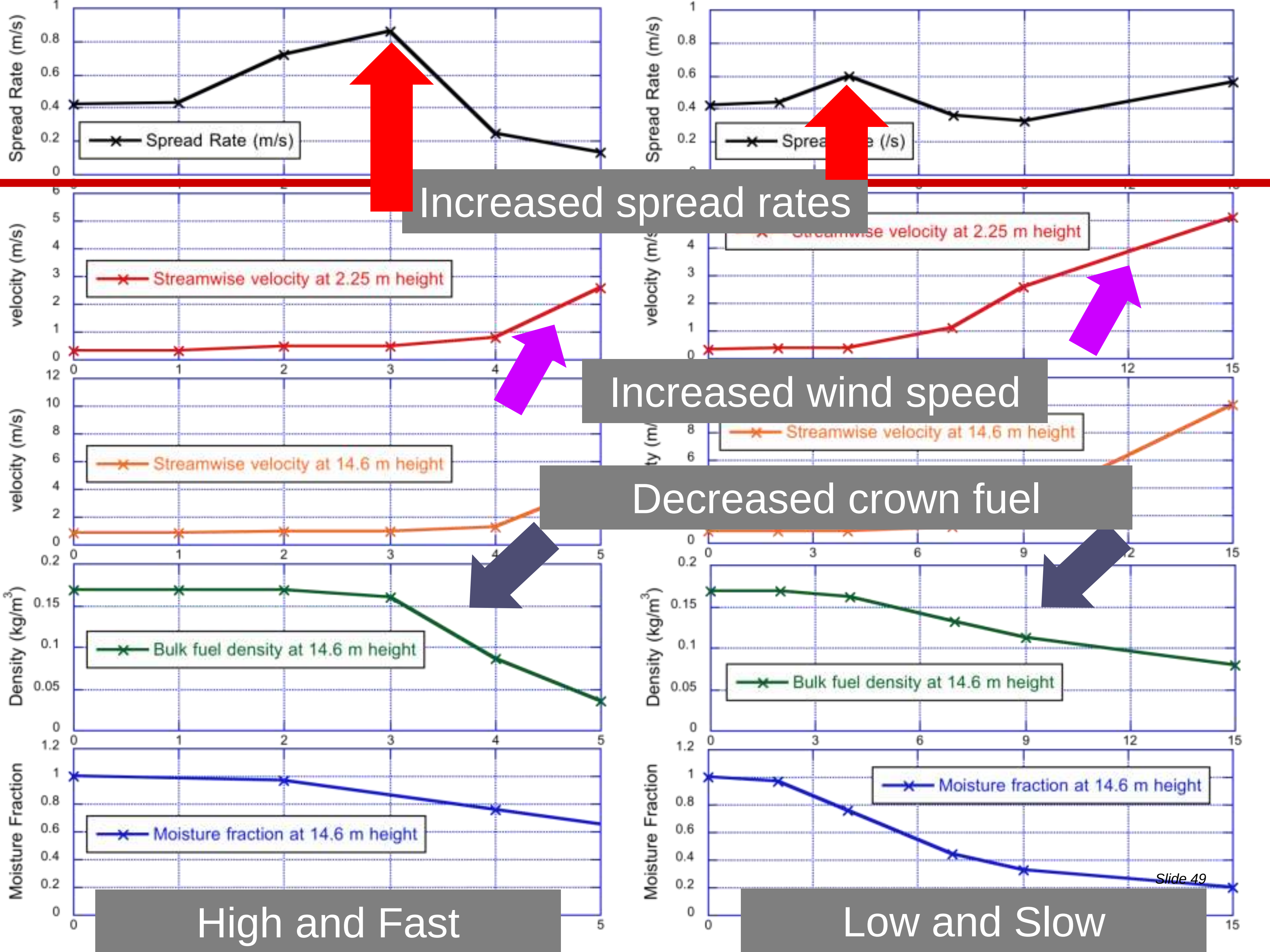


4 yr. post attack



5 yr. post attack



Increased spread rates
Increased wind speed
Decreased crown fuel
High and Fast
Low and Slow
Spread Rate (m/s)
Streamwise velocity at 2.25 m height
Streamwise velocity at 14.6 m height
Bulk fuel density at 14.6 m height
Moisture fraction at 14.6 m height
velocity (m/s)
Density (kg/m^3)
Moisture Fraction

Conclusions

Conclusions: MPB & fire

Immediate (point in time)

- MPB attacks significantly affect flammability in red stage
- “Goldilocks zone” – lots of factors can influence – difficult to predict. Be cautious!

MPB fuel changes over time

- dependent on nature of attack in space and time, stand structure etc.
- Complex: fuel continuity, wind field dynamics, surface fuel loads and crown fuel flammability are ALL in flux

Strong need for continuing research

- Spotting, fire brands, fuel change /microclimate dynamics

Fire Modeling: take home messages

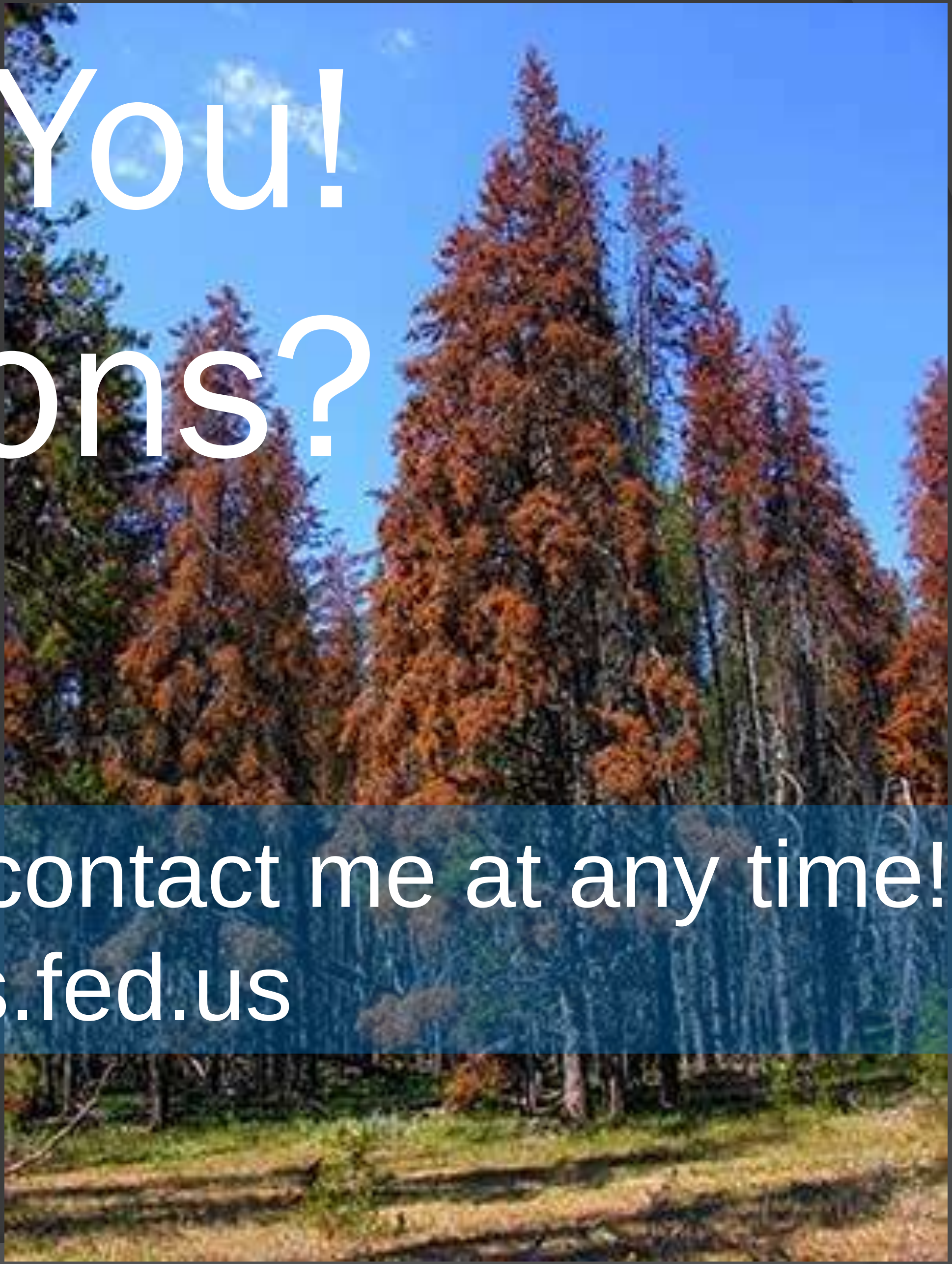
Operational fire models

- – have issues w MPB fuels -- continue to use -- but with wider margins of error

Dynamic fire models

- can provide more detailed information for evaluating such complex issues.
- Need to start developing greater capacity to use these models in management

Thank You!
Questions?



Feel free to contact me at any time!

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